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Courtesy of Calvin W. Hendrick, Chief Engineer, Sewerage Commission, Baltimore, Md.

CONSTRUCTION OF LARGE OUTFALL SEWER, BALTIMORE, MD.

View showing method of reinforcement

Radford's Cyclopedia of Construction

Carpentry, Building *and* Architecture

A General Reference Work on

MODERN BUILDING MATERIALS AND METHODS AND THEIR PRACTICAL APPLICATION TO ALL FORMS OF CONSTRUCTION IN WOOD, STONE, BRICK, STEEL, AND CONCRETE: INCLUDING ALSO SUCH ALLIED BRANCHES OF THE STRUCTURAL FIELD AS HEATING AND VENTILATING, PLUMBING, ELECTRIC WIRING, PAINTING, CONTRACTS, SPECIFICATIONS, ESTIMATING, STRUCTURAL DRAFTING, ETC.

Based on the Practical Experience of a
LARGE STAFF OF EXPERTS IN ACTUAL CONSTRUCTION WORK

Illustrated

TWELVE VOLUMES

THE RADFORD ARCHITECTURAL COMPANY
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Radford's Cyclopedia of Construction

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Bibliography of Construction

BEING A SELECTED LIST OF STANDARD WORKS COVERING VARIOUS PORTIONS OF THE GENERAL FIELD OF CONSTRUCTION

In addition to the vast store of up-to-date practical information never before published, the editors have embodied in the Cyclopedia of Construction the cream of the world's best literature in this field, giving in condensed form the substance of everything essential in the experience of the past to enable the worker of the present to meet every problem likely to be met with under the conditions of ordinary practice.

For the sake, however, of those who may be interested in pursuing further study along various special lines, we furnish a list of important works that have appeared covering different portions of the field.

In this connection, the editors wish to express their thanks to American manufacturers and dealers in the machinery and materials of construction, as well as to proprietors and patentees of various special mechanical devices and processes, for valuable data, illustrations and suggestions.

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Preface

THE Building Industry, in its various branches, is more closely identified than any other with the marvelous engineering progress of the present day and the untold possibilities of the future. To put all classes of workers in familiar touch with modern methods of construction and the latest advances in this great field, and to bring to them in a form easily available for practical use the best fruits of the highest technical training and achievement, is the service which the CYCLOPEDIA OF CONSTRUCTION aims to render.

The work is pre-eminently a product of practical experience, designed for practical workers. It is based on the idea that even in the larger problems of engineering construction, it is not now necessary for the ordinary worker in concrete, or steel, or any other form of material, to attempt the impracticable task of exploring all the highways and byways where the trained engineer or technical expert finds himself at home. The theories have been worked out; the tests and calculations have been made; observations have been recorded in thousands of instances of actual construction; and the results thus accumulated form a vast treasure of labor-saving information which is now available in the shape of practical working rules, tables, instructions, etc., covering every phase of every construction problem likely to be met with in ordinary experience. This is perhaps most apparent in the sections on *Cement and Concrete Construction, Plain and Reinforced.* To this subject, on account of its supreme importance as a structural factor of the present day, three entire volumes are devoted, embodying the cream of all the valuable information which engineers have gathered up to date. Much of this practical information now presented in this Cyclopedia, has never before been published in any form. By its use,

anyone is enabled to take advantage of the vast labors of others, and to bring to bear on any problem confronting him the results of the widest experience and the highest skill.

The keynote of the Cyclopedia is found in the emphasis constantly laid on the *practical* as distinguished from the *theoretical* form of treatment, in its total avoidance of the complicated formulas of higher mathematics, and in its reduction of all technical subjects to terms of the simplest and clearest English. Throughout the pages devoted to Steel Construction, for example, the mathematics of the subject have been eliminated to such an extent that *the reader will not find a single instance where even a square root sign has been used.*

In addition to the larger problems of engineering and building construction, one entire volume, as well as many chapters scattered through the work, is devoted to those smaller constructions that are of special interest to the teacher or student of manual training or the home shop worker of a mechanical turn of mind.

Inasmuch as a wider knowledge and a more intelligent grasp of the fundamental principles of construction and design will tend to greater efficiency on the part of workingmen, and to greater economy in production, the purpose of the CYCLOPEDIA OF CONSTRUCTION is one which will appeal strongly, not only to the men themselves, but also to the architectural and engineering fraternity as a whole.

The authors of the various sections are all men of wide experience whose recognized standing is a guarantee of reliability and practical thoroughness.

Table of Contents

CONCRETE FIREPROOF CONSTRUCTION . . PAGE 1

Floors—Cinder Concrete—Requirements of Fireproof Buildings—Reinforced Concrete and Hollow Tile—Historical Development—Stilted Beams—Simple Form of Floor—Wood Joists in Concrete Floors—Trussed Lintels—Beam Reinforcement over Supports—Girders Framing into Steel Columns—Clamps for Forms—Shaft-Hanger and Socket Inserts—Vaughan Floor—Steel Clips and Tie-Rods—Two-Way Reinforcement—Reinforced Brick Construction—Pile Foundations—Comparison of Concrete and Wood Piles—Steel Sheet Piling—Method of Placing Rods and Forms for Floors and Beams—Forms for Roofs—Column Forms—Expansion and Contraction—Prevention of Cracks—Factory vs. Field-Made Reinforcement—Typical Specifications for Reinforced Concrete—Official Report on Reinforced Concrete

CONCRETE BRIDGES AND CULVERTS . . PAGE 77

Classification of Bridges—Advantages of Concrete for Bridge Construction—Dictionary of Bridge Terms—Railroad and Highway Arch Bridges—Walnut Lane Bridge, Philadelphia, Pa.—Beam Bridges (Girder and Slab)—Classes of Loadings—Standard Details for Highway Bridges—Track-Elevation Bridges—Ballasted Floors—Column Footings—Columns and Cross-Girders—Concrete Decks—Slab Forms—Railway Trestles—Concrete Pile Trestles—Viaducts (Girder and Arch)—An Ocean Viaduct—Culverts (Box, Arch, Pipe)—Details of Standard Culvert—Design of Culverts—Reinforced Culvert Pipe—Cost of Cast-Iron and Concrete Pipe—Design of Abutments—Details of Standard Abutment—Types of Abutments (Wing, T-, U-, Arch, etc.)—Bridge Piers—Details of Standard Railroad Bridge Pier—Forms for Standard Pier—Bridge Floors—Design of Slabs—Rules for Reinforced Concrete Bridge Construction—Steel Reinforcement—Aesthetic Appearance—Face Work—Waterproofing and Expansion—Forms—Arch Centers—Engineering Supervision—Contractor's Plant—Concreting Materials—Block and Mass Work—General Points on Concreting—Freezing Weather—Specifications for Design of Bridges—Standard Rules for Bridge Masonry and Reinforced—Concrete Bridge Design—Specifications for Bridge Floors—Superintendence and Inspection—Specifications for Labor and Materials—Dimensions and Costs of Various Structures—Cost of Painting—Table of Average Costs of Labor and Materials for Various Classes of Bridge Work

REINFORCED CONCRETE RETAINING WALLS . PAGE 246

Back-Filling—Angle of Repose—Resistance to Overturning—Gravity Walls—Walls of L- and T- Section—Counterfort Walls—Details of a Typical Construction—Sectional Forms for Reinforced Wall—Specifications for Materials

REPRESENTATIVE CONCRETE STRUCTURES . PAGE 264

Bridges, Trestles, Viaducts, Culverts, Retaining Walls—Large Factories—Auditorium—First Concrete Skyscraper—Modern Apartment House—Modern Hotel—Cold Storage Plant—Train Shed—Observatory—Boat-House and Garage—Baseball Grand Stand—Coal Hopper—Concrete-Lined Tunnel—Reinforced Concrete Sewer

MISCELLANEOUS APPLICATIONS . . . PAGE 285

Large Coal Pocket—Water-Intake—Chimneys and Smoke-stacks—Water-Tower—Lighthouse—Vats—Penstocks—Reservoirs—Dams—Conduits and Sewers—Shaft Lining—Mine Tunnel Support—Concrete Railroad Ties—Telegraph and Telephone Poles—Docks and Piers—Galveston Sea-Wall—Fort St. Philip Sea-Wall—Burial Vaults—Bath-House

INDEX . . . . . PAGE 335

PART OF FINISHED SECTION OF REINFORCED CONCRETE SEA-WALL AND BOULEVARD NEAR PAVILION, GALVESTON, TEXAS.

Cement Construction

Fireproof Construction

FLOORS

Ten years ago the public knew comparatively little of the merits of cement concrete for fireproofing purposes. There was at that time a greatly increased demand for a homogeneous fireproofing material which could be scientifically and expeditiously made; which would become uniform throughout the floor, in irregular places as well as in square panels; which would unite with and protect all parts of steel members from rust as well as from heat; which could be designed to carry any desired load; which could be made in any shape to suit conditions; which could be made in the lightest forms to save the weight of supporting steel.

Since the New York City building laws of 1899, every form of fireproof construction made of cement concrete has had to pass very rigid tests prescribed. All the cement concrete fireproofing now installed in New York City has been subjected to the several tests and has had the approval of the Superintendent of Buildings.

The requirement of four hours of heat much higher than ever attained in a building conflag-

ration, followed by the regulation stream of cold water under high pressure, all on a loaded full-sized floor panel, finally loaded to 600 pounds per square foot, was sufficient evidence of the merits of the material, as a fireproofing, to everyone witnessing these tests.

After the fire test, and the approval of the construction, any such flooring, designed to carry more than a safe floor load of 150 pounds per square foot, was subjected to a load test of ten times the safe load required. The testing of this form of construction was persisted in by the Department of Buildings, by architects, and by engineers for several years, and the success of these tests was phenomenal to all concerned.

On account of the lightness of cinders and the peculiar elasticity of the concrete from them, to expand and contract in resisting heat, **cinder-concrete fireproofing** has largely been used for floor-slabs between steel beams.

Cinders make good fireproof concrete and this material may be used for suspended ceilings and as a filler on top of slabs between furring strips. Sometimes cinders contain unconsumed coal, which is bad when concrete is mixed wet, and is a dangerous element in case of fire. Cinder concrete should be used strictly as fireproofing and not as a structural material. Used in the latter way, it is costly and dangerous. Sometimes a 1:2:4 mixture is used with a fiber stress of 200 pounds per square inch (thus classing it with burnt clay), but it is not good practice, so

cannot be recommended. The cinders should be carefully selected and freed from ashes, etc. In the majority of cities, cinder concrete cannot be used in spans exceeding 4 to 6 feet. When greater spans are permitted, they are never more than 10 feet, and must be designed after testing a sample slab or beam to destruction, and using data thus obtained with a factor of safety of ten. The ultimate strength of good, well-made cinder concrete is about 900 pounds per square inch in compression at the end of thirty days with a 1:2:4 mixture.

Improvements in recent years in the practical manipulation of centering, mixing, handling, and reinforcing cinder concrete have greatly facilitated and cheapened its construction for fireproof floors. It is now recognized as one of the speediest and most convenient forms of floor construction. There are at present no fireproof contractors—not even those who formerly used other kinds of concrete exclusively, who do not construct largely of this material.

Illustrations of solid concrete and cinder concrete filled fireproof floors may be found in many of the figures and systems shown in this volume. Special reference might be made to Figs. 98 and 103, in the preceding volume.

A building to be fireproof must be so constructed that it is not only non-combustible, but also that it will not be seriously damaged by the burning of its contents. That is, a fire-resisting

building material should fulfill the following requirements:

1. It should be non-combustible.
2. It should undergo no molecular change in a fire that will impair its strength or change its form.
3. It should be possessed of abundant strength and should be so applied that the expansion and contraction due to rapid heating and sudden cooling will not destroy it or impair its usefulness.
4. It should be a poor conductor of heat.

An excellent combination of all the above named is claimed for several types of **reinforced concrete and hollow tile construction** as it is to-day applied. This style of construction, as shown in Plate 14, and Figs. 63 and 100, in the preceding volume—a combination of reinforced concrete joists and hollow tile **separators** (as they are called)—has recently developed very rapidly as a substitute for solid reinforced concrete. It is claimed that tile floors of this type tend to do away with surface condensation of moisture in the air, due to sudden changes of temperature, since they are of lighter construction and respond more quickly to changes than the solid floors.

The tile in this type of floor are set loose upon the centering before the concrete is placed. When the concrete is poured the end joints are imperfectly filled, which is an advantage since the tile have no structural duty to perform, and are thus free to expand when heated, eliminating the possibility of losing their exposed webs, as they are apt to do when built into flat arches.

If the tiles used are porous, they should be thoroughly wet before the concrete is placed, to prevent their soaking up the water in the concrete.

A very notable example of this type of construction is the Marlborough-Blenheim Hotel at Atlantic City, N. J., shown later.

It may be surprising to some to know that reinforcing with cement to secure fireproof floors was practiced in England as early as the middle of the last century, and even earlier. James Frost patented "a new method of casting or constructing floors and ceilings, etc.," in 1822, and the mode of procedure he described as follows:

"Ceilings, whether arched or otherwise, are divided into compartments by iron ribs, these being furnished at the lower parts with small rims or mouldings to receive and support such compartments; and the moulds must be surcased (coated) inside before use with some substance which will prevent adhesion thereto of the materials employed for the work, the moulds being removed, of course, as the materials harden.

"The moulds are fixed by means of supports or braces in the situation of the structure required, so as to bound exactly the surface of the intended work. The complete structure may then be formed by using a quick-setting calcareous cement, having hard and durable substances embedded therein, as for example, Roman cement mixed with bricks, tiles, stones, gravel, or shingle."

When Mr. Frost wrote this description Chicago was a frontier village. This man was one of the pioneers of the cement industry. He established the first manufactory for the making of Portland cement on the Thames, and in 1840 he introduced another fireproof floor made in

the following manner: earthenware tubes two and a-half inches square were made by a machine in ten-foot lengths, and, previous to being burned, were cut into one-foot lengths. A centering, or platform was erected, upon which two courses of these tubes were laid at right angles to each other, embedded together with neat cement. The surface was finished with cement or tiles. This arrangement was said to be sufficiently strong for any ordinary load up to ten feet between supports (Fig. 1).

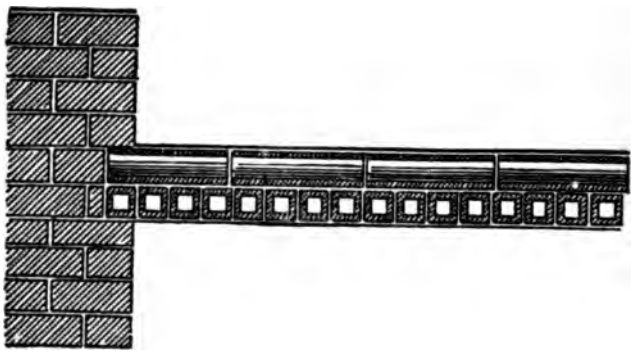


Fig. 1. Tile Floor.

Probably Mr. Frost derived his idea of this form of floor from a custom at one time of forming coverings to areas and forecourts by bedding three courses of roofing tiles together with cement, breaking joints as a matter of course, with spans up to eight or nine feet being usual. Louden in his "Encyclopedia of Cottage and Villa Architecture," published nearly seventy years ago, recommends this arrangement for floors and roofs.

In 1867 Moreland patented a system of floor construction in which curved iron or steel trusses rested on the bottom flanges of iron beams for the purpose of suporting galvanized corrugated-iron sheets on which concrete was deposited, and floor-boards nailed to wood strips fixed to the

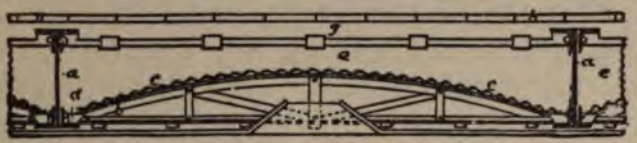


Fig. 2. Moreland's Floor.

joists. In Fig. 2, **a a** are steel beams; **b**, curved truss; **d**, bricks in a continuous line for the ends of the corrugated sheets to rest on; and **e**, concrete. The arrangement was varied to suit special requirements, wood ceiling joists being used if necessary.

The floors constructed of concrete in 1870 and for some years after, were of an ordinary type, concrete deposited on a platform supported on wood centers, which were released

Fig. 3. Stilted Beams.

after an interval of a week or two and used again elsewhere. Spans of twelve feet or more were usual. Some amusing episodes took place when first floors of this character were executed. It was useless to try and persuade workmen that

it was quite safe for them to go beneath to strike the centers; one asked seriously if any provision would be made for his family in case he got killed.

Subsequently some adopted the plan of stilting the beams (Fig. 3), so as to give a greater thickness of concrete over the joists, where headroom permitted, and also flat floors five or six inches in thickness for spans of ten to twelve feet.

The simplest form of concrete floor is formed by fixing steel joists two or three feet apart, and filling in concrete flush with the top and bottom

Fig. 4. Simple Form of Concrete Floor.

flanges, upheld by a temporary platform or centering beneath, as Fig. 4, which came into use almost simultaneously with the adoption of concrete walls, 1865-6.

But as with walls, so with floors; very little care or common sense was taken in their construction, and with the usual result; one at Portsmouth collapsed in 1876, killing four workmen who were beneath; similar accidents took place in other parts of the country, and concrete got a bad reputation.

Where the joists were much deeper than was required for the concrete filling, earthenware

tubes were sometimes embedded longitudinally in the concrete, a system based on Beadmore's invention in 1848, for reducing the weight of the

Fig. 5. Wood Joists on Concrete Floor.

floor. Another method to effect the same object was to fix wood joists on top of the concrete (as in Fig. 5), a very simple arrangement which would occur to most people, but which could scarcely be called a fire-resisting floor but a fire-resisting ceiling, which in case of fire might prevent its upward progress. Still another method was to notch the wood joists over the steel joists with a view of giving some elasticity to the floor (Fig. 6). Neither of these arrangements prevented dirt, dust, and floor washings from finding their way through the joints of the floor boards, and there finding a resting place for generations to come; and from a sanitary point

Fig. 6. Another Arrangement of Wood Joists.

of view, they were no improvement on the wood joist and ordinary floor board system.

Concrete and reinforced concrete structures have been given the highest endorsement any

building material ever received—that of the government itself. The United States Geological Survey issued a bulletin calling attention to the report of the commission of experts appointed shortly after the San Francisco earthquake and fire to investigate fireproofing. As indicated in the bulletin, concrete is accorded first honors among fireproof materials.

Investigations made by three of the most competent structural experts in the country have led them to the conclusion that there are

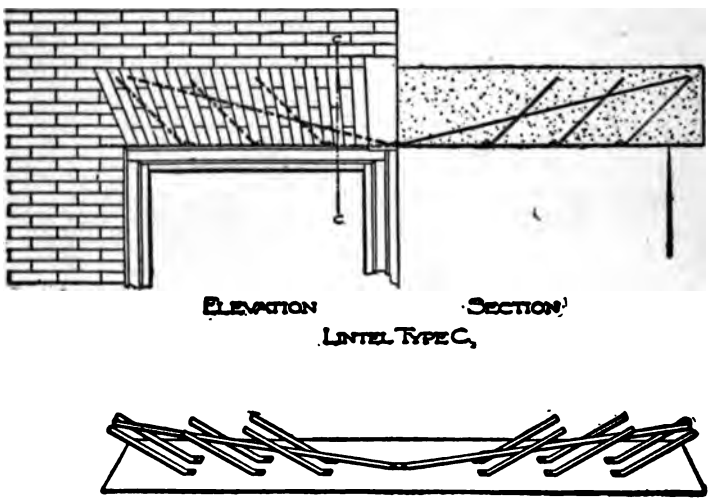


Fig. 7. Trussed Lintel.

no absolutely fireproof buildings. Not that fireproof buildings are impossible, for, according to these experts, structural materials may be so selected and used that adequate fire protection is practically assured; but in the effort to cheapen construction in order to obtain greater

interest on investments, owners of buildings have neglected or ignored perils to lives and fortunes.

The recommendations of the experts as to the essentials of fireproof construction are definite and positive. High, steel-frame office buildings, properly braced, are declared to be stable and reliable, and concrete and reinforced concrete structures are placed high among materials well adapted to withstand earthquake and fire; while hollow tiles and hollow concrete, although not in the past universally successful, may be so employed as to yield most satisfactory results. Concrete floors with metallic mesh reinforcements are strongly recommended for strength

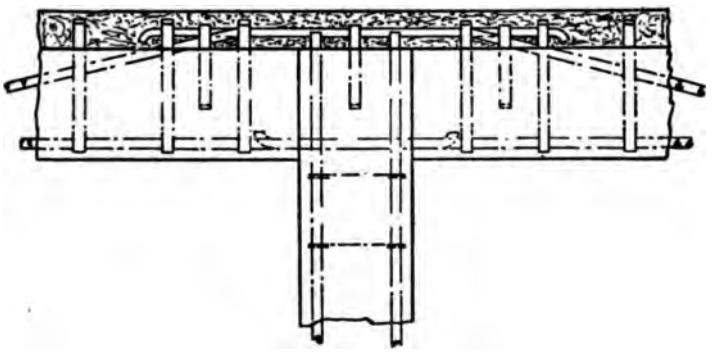


Fig. 8. Typical Reinforcement of Beam over Support—Hennebique System.

and fire-resistance; and wire glass, metallic rolling shutters, and metal sash have proved such excellent fire protectors that wise economy demands their use in every important building.

Plate 1 shows a detail of **window framing into a reinforced concrete lintel beam;** while Fig. 7 shows a trussed lintel which is claimed to be cheaper than structural steel and more effective.

Fig. 8 shows a common way of extending reinforcing rods over a support in case of continuous floor construction. The top rods take the tension over the supports when the floor tends to deflect or bend in center of span between girders.

Plate 1 shows details of connection for concrete **girders framing into steel columns.**

Fig. 9 shows a **clamp** used in holding wooden forms together during the construction work.

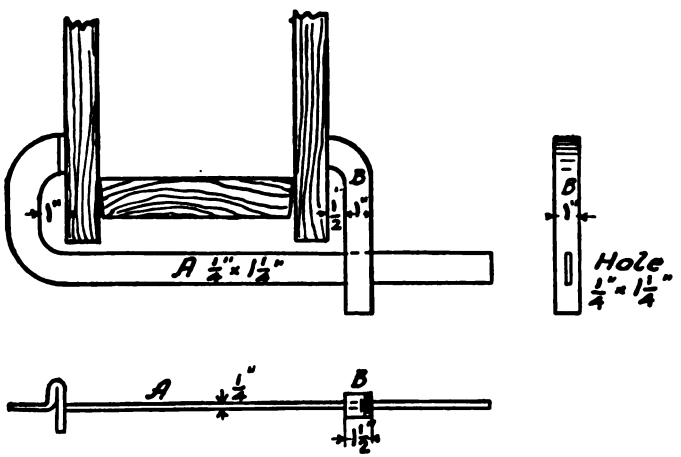


Fig. 9. Clamp for Beam or Small Column Form.

This clamps around the corners of the forms, and, when in place, is set up tight by hitting on free end of bar.

Plate 2 shows a form of **shaft-hanger insert.**

These are attached to the forms during the concrete construction work, and completely embedded in the concrete. The long slot allows considerable variation in the location of the shafting. Standard lengths of these inserts are three feet, but they are made in a single casting in lengths up to six feet.

Plate 2 also shows a **socket insert** for attaching sprinkler systems, fixtures, shaft-hangers, etc., to concrete work. They are made in two sizes, cored and threaded for ½-inch and ¾-inch bolts.

The manner of bonding and laying the individual joists in the **Vaughan system of floor con-**

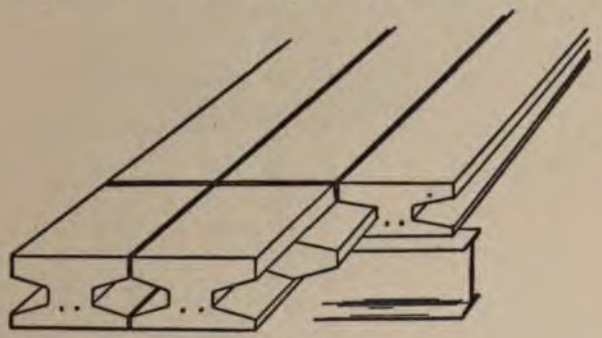


Fig. 10. Vaughan Floor.

struction present a few points of interest which are shown in the accompanying figures. Where there is sufficient head-room, the joists can be placed on top of an intermediate I-beam support, simplifying and cheapening the erection. When the joists are placed on top of an intermediate support, as shown in Fig. 10, a simple and posi-

tive method of tying the two sides together is the use of a cast concrete block fitting into the hollow space between the joists. This block is wrapped once with very coarse burlap. When placed, this is wet down and submerged into a wet mixture of one part cement and one part sand, the meshes of the burlap forming pockets which retain the mixture and prevent it being scraped off when put in place.

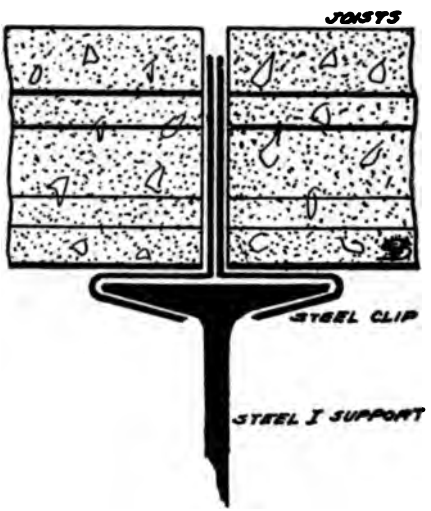


Fig. 11. Use of Steel Clips.

When the joists are placed on top of an I-beam for an intermediate support, two steel clips can be fastened over the top flange of the I, and the ends of the joist placed against their turned-up ends, as shown in Fig. 11. This provides a method of transmitting the transverse floor loads from the joists to the supporting beam.

and would prevent its slipping to one side under any conditions.

The continuity bar or tie-rod shown in Fig. 12 is to take care of any negative bending moments due to the girder support at this point. This is necessary when a granolithic or any solid cement or stone finish floor is used, preventing absolutely thereby unsightly cracks. Fig. 12 shows the position of the bar when the joists are placed with their top flange under the top flange of the I-beam.

When floor-joists of this type are used throughout a building, it is advisable to **tie the walls together.** At

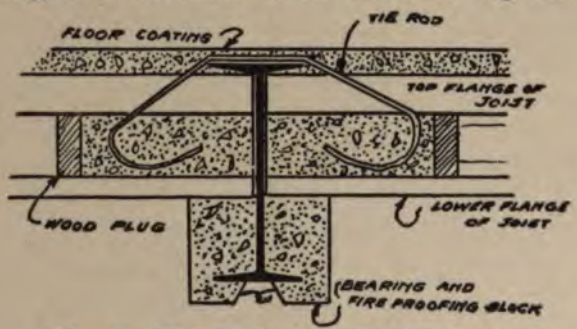


Fig. 12. Tie-Rod Used in Vaughan System.

intervals of about 20 feet or at the intersection of interior columns, two joists can be separated by a space of about 8 inches or a full width of a column if desired. A single board placed underneath this space and supported by props—the ordinary method of supporting centering—will form a false floor on which to pour wet concrete. Long rods extending the full width of the building and turned into the wall, should be placed in the space between the joists, which should then be filled with concrete, flush to the top of the joist.

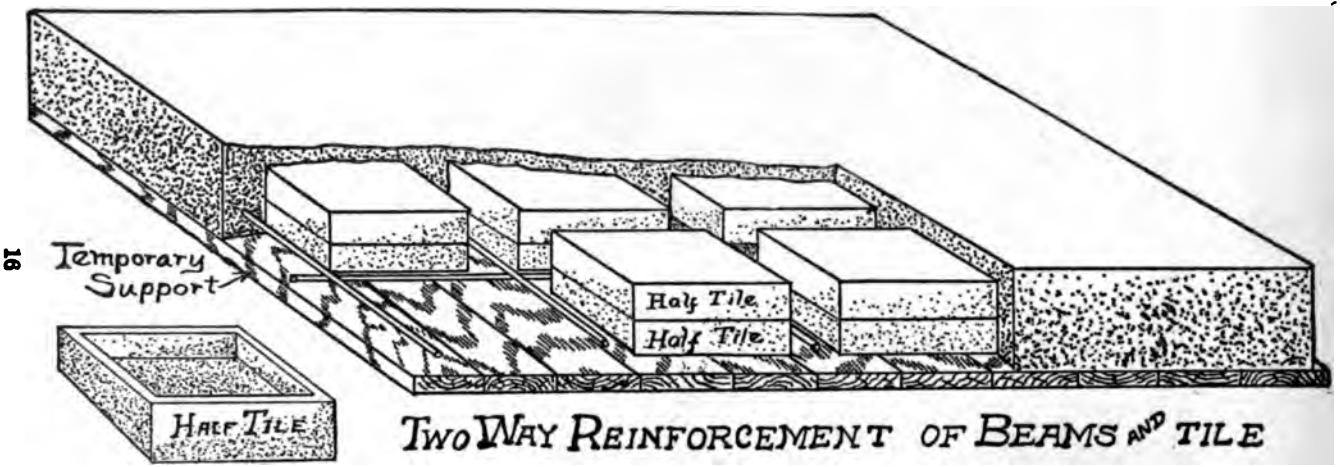
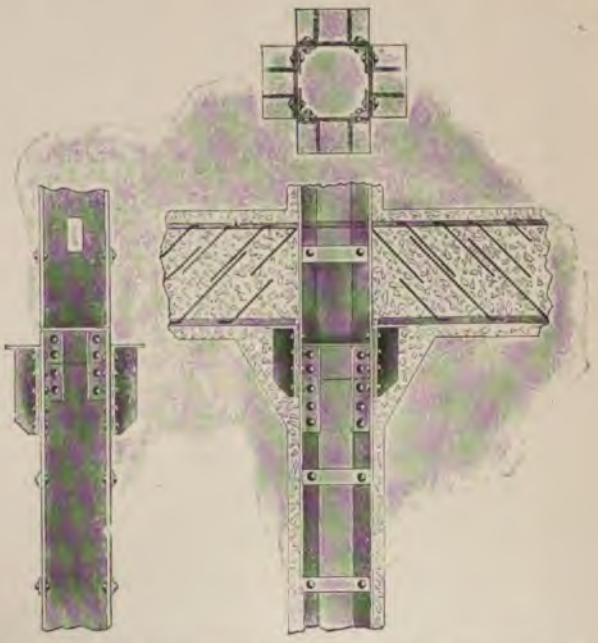


Fig. 13. Two-Way Reinforcement of Beams and Tile.

DETAIL OF WINDOW FRAMING INTO CONCRETE LINTEL LEAM.



DETAILS OF CONNECTIONS FOR CONCRETE GIRDERS FRAMING INTO STEEL COLUMNS.

PLATE 1—CEMENT CONSTRUCTION.

A short tie-rod can be used by the following method: The top flanges of the two joists should be broken away for about 6 feet next to the wall. In this space, lay a tie-rod about 9 feet long, with one end bent into the wall for about 15 inches, and the other end curved into a hook shape. A wood block should be placed between the joists, filling the hollow space, to serve as an end stop, and the concrete poured in to fill up this opening. This method of tying will serve as well as the first method, when the interior ends of the joists are tied to the beams and columns in a suitable manner.

Fig. 13 shows a type of **strong and light floor.** In concrete fireproof floor construction we have a heavy dead load (weight of floor) on long spans, which, added to the live load, makes much additional cost on long-span work; therefore, the combination system of running beams one way, separating them with rows of hollow clay tile, has become popular; but this does not tie or bond the floor together like a **two-way reinforcement.**

This has led to the design of a **two-way floor-slab** of the beam-and-tile system. The tile, being made of concrete, are 16 inches square, made of a web ¾-inch thick, and have the height of the space required, so that two tile make an air-space or void to reduce the weight of the floor slab.

The centering is but one flat surface, the same as for beam and tile combination of the one-way type, which is much cheaper than the drop beams (panel method) and solid slab of the all-concrete floor.

These tile are spaced four to five inches apart, forming the beams as shown.

Owing to the depth of beam, this is claimed to be one of the best and least expensive systems now in use, the floor being bonded in all directions, as the rods (reinforcing) are tied with wire at every crossing.

Any plain or patented bar can be used, and the hollow concrete tile can be made in moulds or on machines. Thus no delay in waiting for clay tile is necessary, one part of cement to five parts of sand making a very good tile for this purpose. One part cement, two sand, and four of gravel is generally used for the beams.

The height of tile and thickness of floor are governed by the load per square foot and the length of span. A floor, for example, to carry 200 pounds per square foot, and span 20 feet between supports, should have tile 10 inches high (two half-tile of 5 inches each), and have two inches of concrete over them, thus making the floor-slab twelve inches thick, which will weigh about 38 per cent less than a solid twelve-inch slab, or about 92 pounds per square foot.

The plainness of the forms, saving lumber and carpenter work; the depth, saving reinforcing; and the reduced weight and well-bonded reinforcement, make this type of construction economical in many instances. However, the appliances for making the half-tile have much to do with the cost.

REINFORCED CONCRETE BRICK CONSTRUCTION

Joseph A. Hofmann, a California inventor, has offered to the building world a system of **reinforced brick construction** that has been adopted already by many builders who seek a system of construction that will defy earthquakes and other violent forces. His system provides for a perforated cement or clay brick which, when placed in a wall and strung on rods, so to speak, will hold the wall in one mass against

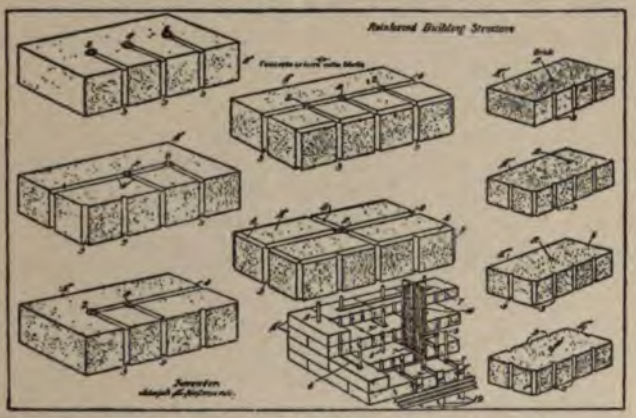


Fig. 14. Cement Brick with Perforations.

any force that may be brought against it. In regard to his system, Mr. Hofmann says:

"These bricks or blocks are laid up in usual break-joint courses, with a suitable filling of cement or cement mortar and metal rods passing through the bricks or blocks and between the blocks. These rods are composed of sections, each four or five feet long, so the bricklayer can pass the bricks over the rod in laying them,

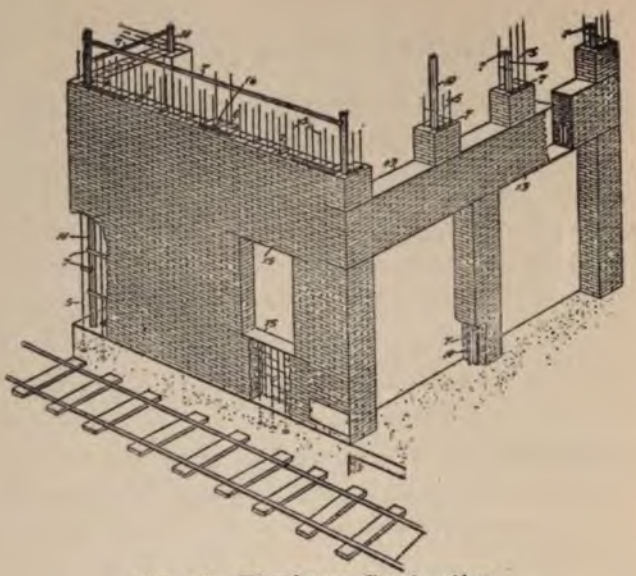


Fig. 15. Warehouse Construction.

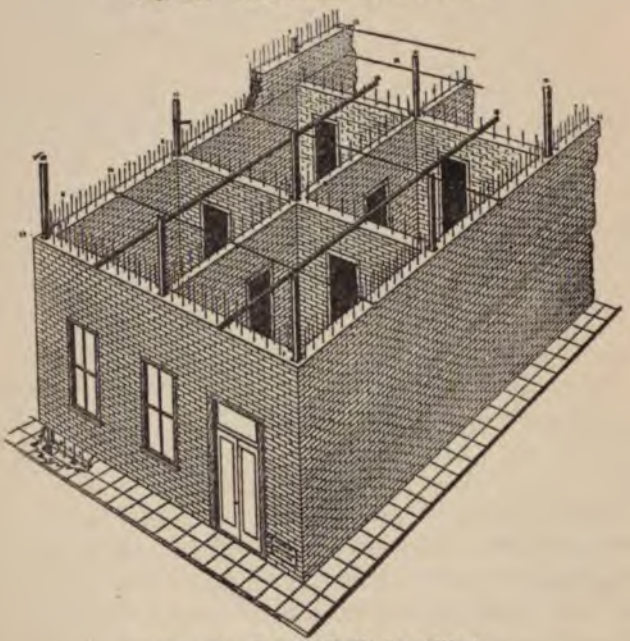


Fig. 16. Partly-Built Dwelling.

and are firmly embedded in the foundation, in various ways; and as the courses reach the end of the section of the rod, another section is added to it by welding, or screwed in a socket connection, or otherwise; the rods being bonded together by a bond-iron. Where the bond-irons (which are made of wire) are used, they fit in a groove. Where flat bond-irons are used, they, being thin, are laid between the bricks either horizontally or vertically; the bond-irons are made with eyes or perforations, through which the rods pass. See Figs. 14, 15, 16, 17, and 18.

"The bricks or blocks may be made either of clay, of cement, or of other material of suitable size and shape, with the perforations of any size or shape, in the center or elsewhere. The rod may be made of steel, iron, or other material of any size or shape desired.

"When the top of the building is reached, the rods pass through a plate of steel, or iron, or other material, of suitable thickness, and are then riveted or bolted firmly, or fastened in any other way most convenient.

"When piers are to be built, as at the corners or elsewhere, a hollow space is left, in which is placed a metal column, which is cruciform in cross-section. This column is bonded to the bricks by the bonding ties, the rods passing through the eye at one end and being riveted at the other end to the column, the edges of the column being shaped to fit the corresponding vertical grooves in the adjacent blocks and the space left open for gas or water pipes if desired, or filled in with concrete or cement.

"This structure is particularly adapted for use in conjunction with a steel frame which is provided with lateral projecting plates at suitable intervals, say at each story, which extend part way between the courses of the brick, and are perforated so as to pass the vertical rods. The walls, being strongly braced across at each story by heavy metal rods or girders, give increased rigidity to the structure, especially in very tall buildings, the

above plates being firmly welded, bolted, or riveted to the cruciform columns or steel frame.

"At a window opening, the frame carries the top and bottom plates; at these window openings the vertical rods are cut and riveted, bolted, or fastened to the plates in any way desired. At occasional intervals the steel frame is bonded to the vertical rods by the bonding ties.

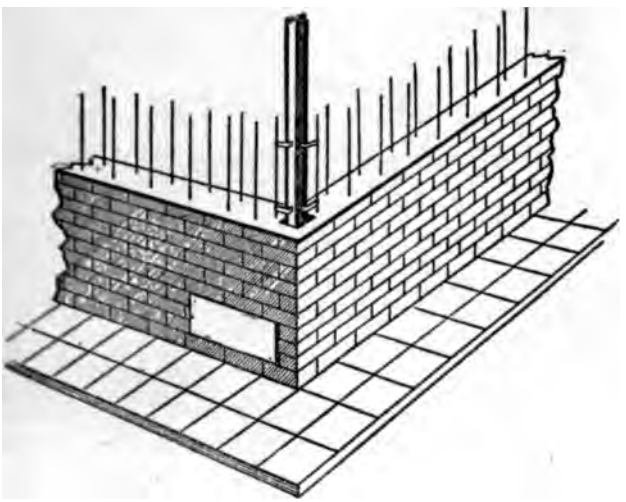


Fig. 17. Corner of Wall.

"The pier columns can be arranged at greater or less intervals in a long wall, according to the character of the building and the strains it may have to undergo, and also when needed to act as a flue or flues for a chimney when the metal column is left out.

"A structure bonded together in the manner indicated, and laid in the best cement or cement mortar, the joints being well grouted, has the extreme of rigidity and staunchness, and is capable of withstanding the severest shocks, twists, strains, and vibrations, rendering the highest buildings proof against the forces of the heaviest winds and storms.

"The partitions between the rooms and hallways can be built of brick, making the structure thoroughly fireproof; and they may be supplied with metal doors, concrete floors, ceilings, etc.; also insuring a sound-proof and vermin-proof building.

"This style of building is particularly adapted for warehouses, dwellings, flats, tenement and apartment

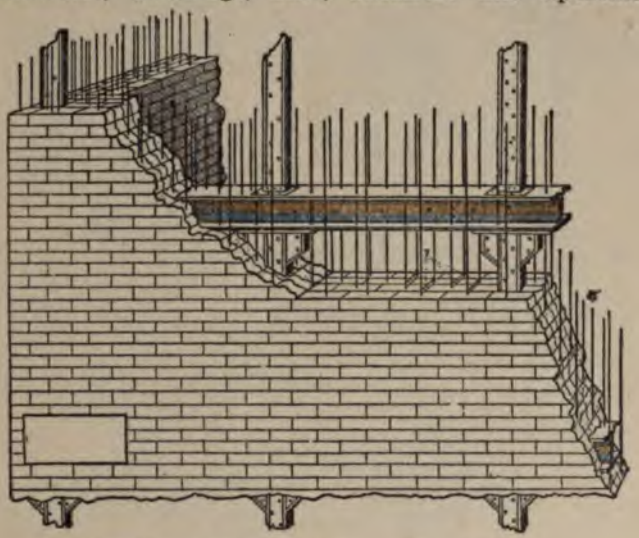


Fig. 18. Wall Built between Cross-Beams.

houses, at about the same cost as that of an ordinary well-built brick building, and a good substantial structure is assured, making it as safe to live in as any frame house or building during an earthquake or cyclone."

PILE FOUNDATIONS

Figs. 19 and 20 show comparisons between the use of concrete and wood piles in foundation work. Fig. 19 shows the smaller number of Raymond concrete piles required to sustain a given load as compared with wood piles under the

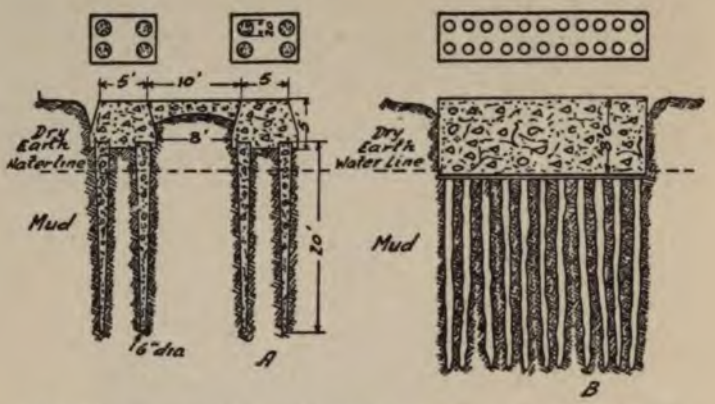


Fig. 19. Raymond Concrete Piles Compared with Wood Piles.

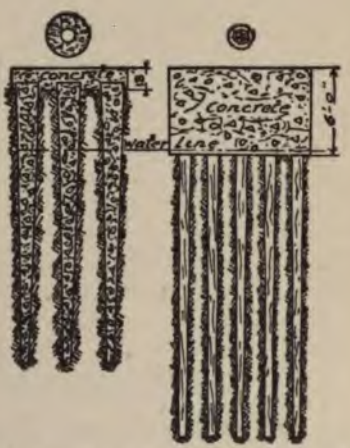


Fig. 20. Relative Economy of Raymond Piles as Compared with Wood.

same conditions. **A** shows the concrete piles in piers joined by concrete arches as built for the J. I. Case Plow Works, Racine, Wis. Single piles and a pier of four piles were weighted, the test load remaining on the piles for six days in

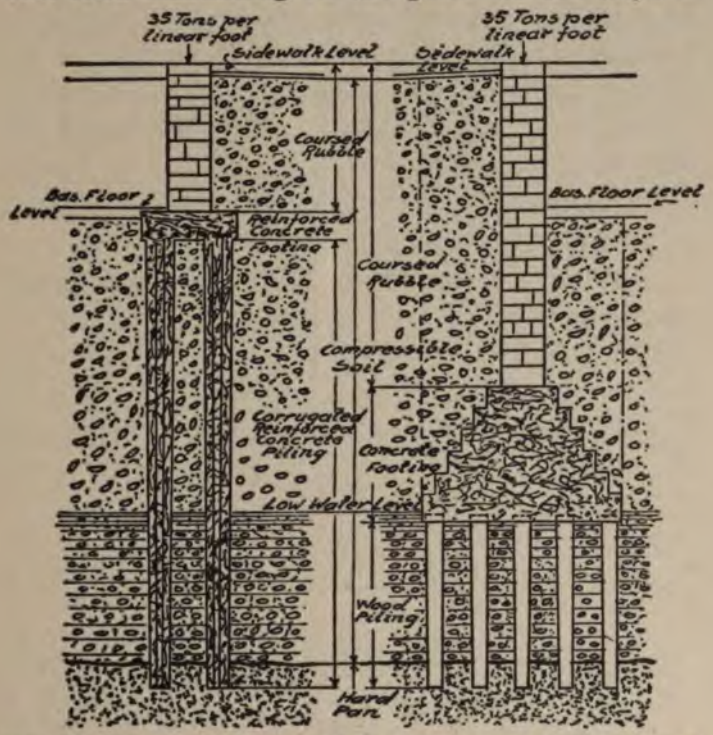


Fig. 21. Comparison between Gilbreth Piles and Ordinary Wood Piles.

each instance, without showing any settlement whatever.

B shows the contemplated wood-pile plan for the same building, the cost of which, it is claimed, would have been fifty per cent more.

Fig. 20 is another illustration of the relative economy of concrete piles and wood piles. Ordinary wood piles average about 12 inches in diameter at the top, and 113 square inches of head surface. Concrete piles, 20 inches in diameter at the top, have 314 square inches of head surface, or 2.77 times that of wood piles. The taper of a wood pile is only about three or four inches from top to bottom, while the taper of a **Raymond concrete pile** is from 10 to 14 inches.

The illustration gives a fair representation of what may be saved by the use of concrete piles. The three concrete piles, each 20 inches in diameter, have a bearing surface of 942 square inches, while the five wood piles, each 12 inches in diameter (which is a fair average) have a bearing surface of only 565 square inches. Note the additional concrete required on top of the wood piles, which must also be cut off below the water line to insure their permanency. Furthermore, in using wood piles it is frequently necessary to

Fig. 22. Wemlinger Corrugated Steel Sheet Piling.

drive sheet piling around the trenches in order to make the excavation to water line.

Fig. 21 shows a similar comparison in construction work, showing the difference in the amount and form of foundation when **Gilbreth**

piles are used instead of the ordinary wood piling.

The **Wemlinger Corrugated Steel Sheet Piling** is built in many types and sizes. The two types shown in Fig. 22 represent the **single-lap** and **double-lap** forms. The single-lap form is most suitable for sewer and water-pipe trenches, open cuts for railroad tunnels, foundations, trenches, and such general excavation work as does not require absolute water-tightness. The double-lap form is used for work requiring any degree of water-tightness, as in cofferdams, bridge piers, etc.

The clips shown in the figure provide for the locking together of the sheets so that they may be driven as a solid sheet. In some forms of this product, the clip is omitted, the piling simply overlapping one corrugation on each sheet.

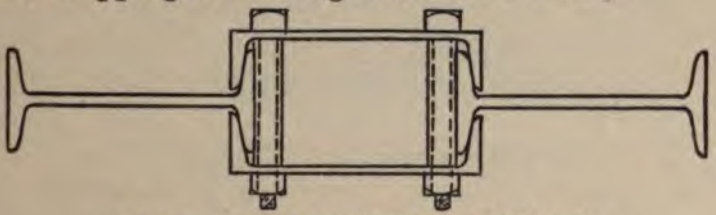


Fig. 23. Jackson Interlocking Steel Sheeting.

The **Jackson Interlocking Steel Sheeting** is especially adapted for cofferdams, bulkheads, dams, bridge foundations, lighthouse foundations, piles, caissons, locks, wharves, cribs, forts, shafts, shields for tunnels, and for any other construction work in deep water where it is necessary for the piling to be perfectly water-tight.

The sheeting can be driven through clay, sand, gravel, quicksand, and even into shale rock, and can be used over again repeatedly.

Fig. 23 shows a section of patent interlocking steel sheeting, Style No. 1. This is made perfectly water-tight by filling in the channels with clay or cement grout. It can be made up of either 15-in. 33-lb. channels and 15-in. 42-lb. I-beams, weighing 49 lbs. per square foot, or 12-in. 20½-lb. channels and 12-in. 31½-lb. I-beams, weighing 40 lbs. per square foot; and is espe-

Fig. 24. Stilted Beam.

cially adapted for heavy construction work. In other styles of this sheeting, instead of clay or cement, wooden pieces are driven in between the channels, and produce a water-tight joint by swelling.

PLACING OF FORMS

In an article on the placing of rods and forms for concrete floors and beams to secure the best results, Thomas Potter says:

"It is a desirable practice to wash the rods or bars with liquid cement before they are embedded in the concrete; the rods should be clean and cold, and the process not done in the sun. If the rods are damp or moist, so much the better, and the cement should be of the consistency of cream.

"'Forms,' or the temporary wood casings used for upholding the concrete in a soft state, and called in America 'falsework,' take away much of the carpenter's trade by dispensing with wood beams, joists, and floor boards; but in many instances this is more than made up for by the large amount of labor and materials necessary for their construction, more especially where beams are numerous. Where no reinforced beams are required, or steel beams are employed, the falsework for the actual floor is much simplified; the under side is straight throughout, and it is an easy matter to arrange the falsework necessary to support the concrete, either by props beneath or suspended by bolts attached to timbers over;

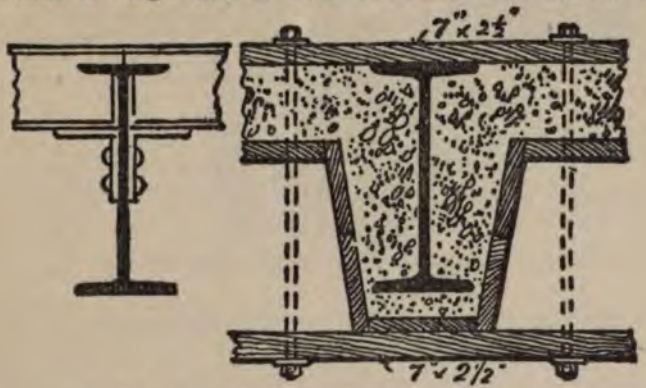


Fig. 25. Forms for Encasing Steel Beams.

but it is often the case that the concrete is not of the same thickness as the joists are in depth, so they have to be stilted with concrete, as shown in Fig. 24. As thinner concrete for floors than formerly is becoming general, stilting is usually adopted where main steel beams are employed a considerable distance apart, and small transverse joists are attached thereto to support the concrete, iron angle bearers riveted to the beams being general at one time, as in Fig. 25, but stilting is preferable. It costs less; it is a protection in case of fire; it assists to stiffen the beams and to strengthen them, and reduces

their flexure. With a view to protecting the bottom flanges of the steel beams, it is sometimes specified that they shall be encased with one inch or two inches in thickness of concrete, as in Fig. 25. With the forms for the stilting in position, this is somewhat difficult; the concrete is simply pushed under with a piece of iron or wood crooked at one end. When the forms are released, portions of the concrete often come away with them, and the flanges of the beams are visible, the result being that

Fig. 26. Reinforcing around Beam Flanges.

the bare places are at the first opportunity filled up with a dab of mortar; sometimes coarse grout is run under the flanges. It is doubtful whether the flanges are efficiently protected in this way, and whether a wrapping of expanded metal lathing around the bottom flanges, tucked into the concrete on each side, as in Fig. 26, and plastered with lime and hair mortar, is not very much better. Sometimes steel wires are bent in the form of a stirrup and embedded in the concrete under the flanges, and their ends anchored in the concrete stiltings.

"This is a difficult thing to accomplish, and is very seldom satisfactory.

"Sir M. Shaw, when chief of the London Fire Brigade, said if only an inch of plastering mortar could be made to stay on all exposed portions of steel beams, the danger

from fire through their collapse would be largely minimized.

"Forms for floors are usually kept in place by bolts

Fig. 27. Floor Form.

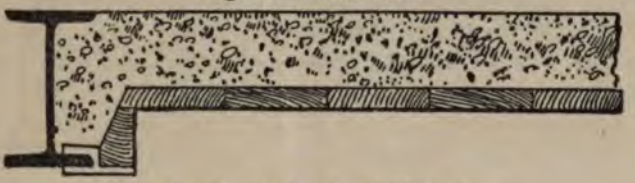


Fig. 28. Iron Clips for Holding Forms.

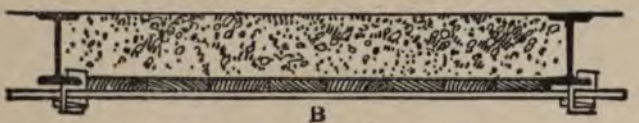


Fig. 29. Another Form of Clip.

attached to wood battens resting on the top of the beams and to others below, as in Fig. 27. Evidence of the trouble caused by so apparently trivial a matter as temporary arrangements to keep the concrete in place until it is set, is to be found in the fact that more than two dozen patents have been taken out with this object alone.

"After experimenting in various directions for the same purpose, I have adopted and patented some very simple methods.

"Fig. 28 consists of tee-iron clips about three inches in length, the webs bent so as to wedge them on the bottom flanges of the beams. Stilting pieces of wood of the depth required bear on the flange of the clip, a few small wedges being used between the wood and

the clip, which, when removed, enable the stilting form to be released.

"Fig. 29 is adapted for floors where the concrete is flush or fair with the bottom flanges of the joists, and the latter are any distance not more than six feet apart. Clip hangers made out of steel bars about 1 by ⅛ inch have a mortise through which iron bars **B** about 1¼ by ¼ inch are passed; the bars are fixed three or four feet apart, and inch boards are laid on them to uphold the concrete. The clips are driven on lightly with a hammer. The small wedges are to allow the bar **B** to be loosened and withdrawn, the boards liberated, and the clips removed.

"The same principle is adopted for roofs where purlins support the concrete, **A** (Fig. 30) being the bar. The object of curving the concrete is to lessen the amount and weight of the concrete without reducing the strength.

"Fig. 31 shows an arrangement of forms necessary for beams and floors. The posts should rest on a floor

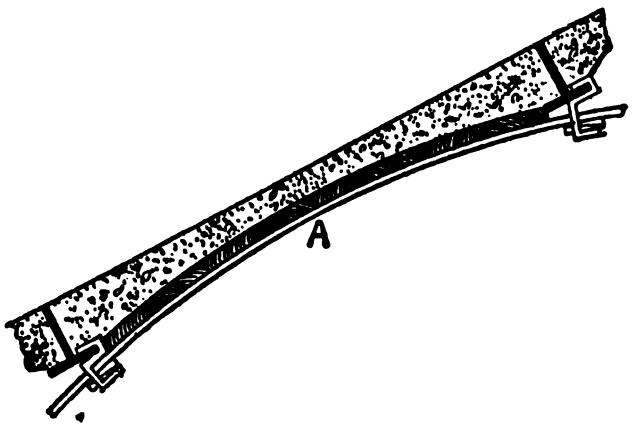
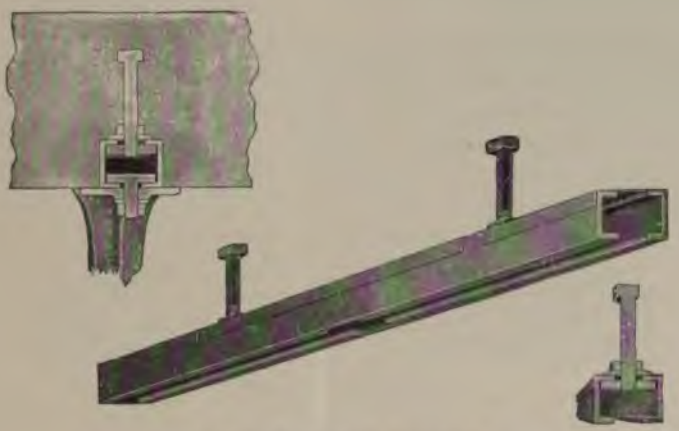
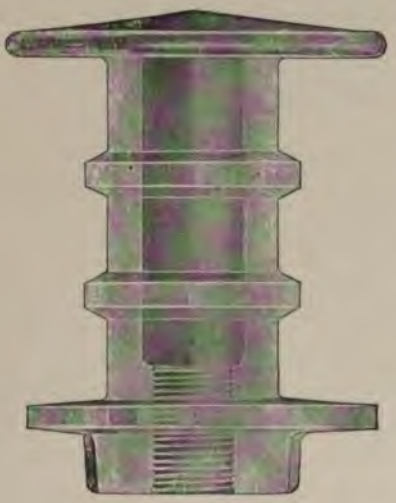


Fig. 30. Forms for Concrete Roof.

of planks at the bottom, and be placed as far apart as may be necessary. A pair of wedges under each post is necessary, and when released and the 2 by 2-inch



SHAFT HANGER INSERT.



SOCKET INSERT.

PLATE 2—CEMENT CONSTRUCTION.

wedges withdrawn, the whole of the timber work gives way.

"It is sometimes the practice to form reinforced concrete beams first, remove the beam forms, erect the floor forms and do the floor concrete as a subsequent process. But this is altogether wrong, as much longer time is required; and, the floor having to be formed on top of the beams, the latter are deeper than necessary, and possess no additional strength. Where concrete beams are

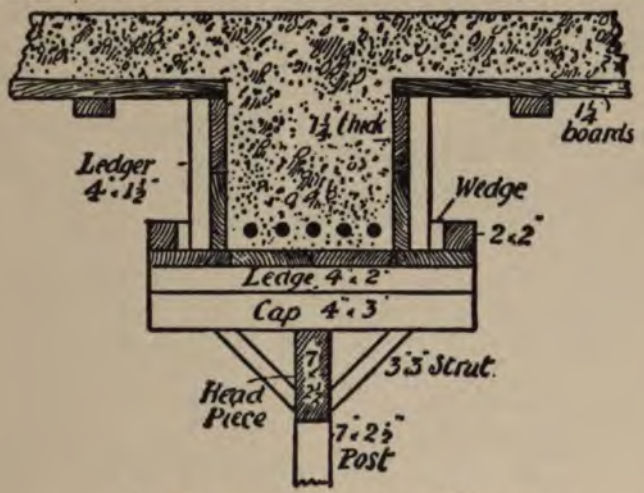


Fig. 31. Forms for Beams and Floors.

not constructed in place, this arrangement is, however, unavoidable.

"Forms for concrete columns should be of a substantial character, or—if of light construction—well and rigidly bound together, as, like water, concrete exercises pressure on all sides. Practitioners differ a good deal in their methods of making forms for columns. My own view for economy and simplicity is shown in Fig. 32, which is a horizontal section of a column form. The sides **A A** are 1½ inches in thickness and strongly ledged together at intervals to prevent the wet concrete from

warping and twisting them. They should reach the full height of the column. **B B** are wood strips or fillets about 2 inches by 1 inch, firmly nailed to **A** the full height of the form, and each in one piece. **C C** are boards dropped in singly as the concrete is being deposited in place. **D D** are light wood clamps correctly made to keep the sides **A A** in position. Necessarily the forms require to be strongly stayed to prevent any divergence from the perpendicular. This arrangement can be applied to the encasing of steel stanchions with wire bonds embedded in the concrete as shown in the horizontal section, Fig. 33.

"The sides **A A** must be watched for alignment; there

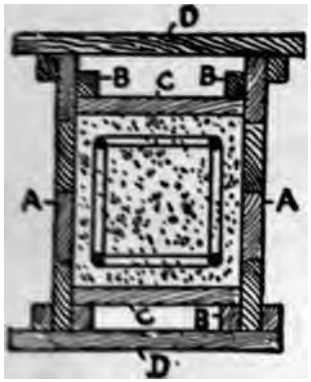


Fig. 32.

Fig. 33.

Column Forms.

is no remedy whatever if they once get out of position and any portion of the concrete has been deposited in place. **D D** are light wood clamps, made so as to require no wedges. When the concrete is hard, the clamps **D D** are easily knocked off with a hammer, which releases the form. The woodwork should then be at once cleaned, and is ready for re-use for another column. The principle can be applied to any form or shape column, and to steel stanchions; and if bond ties are inserted in the concrete at intervals, there is no better way I know of to protect the latter from fire.

"A practical foreman carpenter, possessing common sense, should be quite capable of devising his own forms to suit the numerous requirements of reinforced concrete construction, and possibly better than cut-and-dried rules of instruction. Obviously some slight experience in this direction is an advantage."

Regarding the **use of steel forms** in reinforced concrete construction, Mr. W. L. Caldwell says:

"Wooden forms or centerings for concrete construction are the 'bugbear' of all engineers and constructors, not only on account of their first cost, but on account of the great amount of labor and time required to put them to place and remove them after the concrete has hardened. Furthermore, on account of having to re-cut and readjust the centering so many times to complete a modern building, it is of little value or use for other similar structures—frequently a total loss—and in some cases the contractor must pay for having it hauled from the building. The wise and progressive engineers and contractors are endeavoring to find a more suitable and permanent material, less destructible, to take its place, even though the first cost is not so low, a material which can be used over and over again, thereby producing a great saving.

"It is one thing to design a form for centering, and another to make one that is practical and that can be made on modern machinery at reasonable cost. The thing we must strive for is the minimum amount of steel and labor required to produce a centering that will give maximum results. And this we have attempted to do by forming up sheet steel into certain standard forms so that they may be adjusted to different-sized spans or bays without cutting or fitting.

"The one great drawback to producing a uniform centering is the disregard of uniform spacing of columns, girders, and beams for certain types of buildings, and of regulating the height of stories. It would appear that

the greatest stride that could be made for the success of concrete construction would be to adopt a series of standard sizes and spacings of columns and girders for certain types of buildings. If this could be accomplished, it would materially reduce the cost of all such buildings, as certain engineers and contractors would equip themselves with the necessary appliances to erect these buildings at the minimum cost; and again, other contractors would equip for other classes of buildings which seem best suited to their likings. In this way the whole field would be covered and the very best results obtained, and at the same time the investor would reap the benefit of the cost reduction, and all would be happy.

"Centering can be confined to three types, as follows:

"First, the floors where the whole area interlying four columns is flat on the under side; second, where the area is broken up by two cross-beams into three panels; and third, where the area is divided up by a series of concrete ribs or joists. In all cases the columns may be either round or square, with brackets or plain, and the carrying girders between the columns dropped below the cross-beams, ribs, or interlying area. The sizes of columns and girders should be restricted to four depths and widths for buildings of ordinary design, with a variation of two inches in height for girders and beams, and four inches for diameter of columns, eight inches being the minimum and fourteen the maximum for girder boxes, and four inches the minimum and ten inches the maximum for lateral beam boxes; width of girders and beams in proportion to depth to be determined. Columns may range from twelve inches to twenty-four, with four inches variation—that is, 12-16-20-24 inches. These sizes could be adapted to almost any type of buildings where light or heavy floor loads are to be carried.

"Again, the variation in height of stories should be restricted, allowing four different heights to apply to different classes of buildings.

"Mercantile buildings can be divided into three classes —namely, office, wholesale, and warehouse; manufacturing into two—light and heavy; miscellaneous, such as schools, theaters, churches, and dwellings, into two. If this could be accomplished you can readily see that it would simplify the whole matter, for both the engineer and the contractor, as well as for the manufacturer of

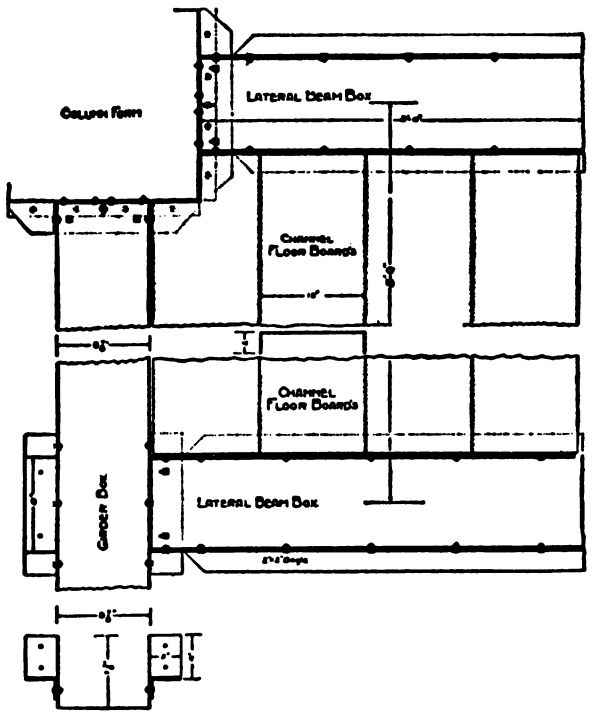


Fig. 34. Use of Metal Forms.
Plan of bay at column showing girder and lateral beams supporting channel floor-boards.

centering. The engineer would determine the size of columns, girders, and beams by the loads to be carried, by referring to the table for certain spacings; and the contractor would only need to invest in two or three sizes

of forms or centering to construct any one type of building. It would resolve itself into contractors confining their operations to certain types, which would be a good thing, both financially and structurally.

"Taking matters as they stand to-day, sheet steel for centering purposes will compare favorably with wood in first cost, and the great saving in labor in putting it to place is certainly apparent to everyone who has seen the steel centering.

"The steel may be shaped for forming either round or square columns, so that they can be removed without injury and in one-fourth the time it takes to remove wooden forms. For each type of construction, the girder boxes are attached to the column forms, and the lateral beam boxes in turn to the girder boxes (see Fig. 34), the distance from the center of the column to the first lateral beam is fixed, say five feet; and the distance between the two lateral beams is variable, to allow for spacing of columns. The lateral boxes carry the flooring over the whole intercolumn area, so that when all are in place the column form, girder boxes, lateral beam boxes, and flooring are level and even, allowing for a uniform slab of concrete over the whole area, bonding with the columns, girders, and beams, and making a homogeneous mass.

"After the concrete has hardened, the cross-beam boxes are dropped, then the steel floor bonds, next girder boxes, after which the column forms are taken off, leaving a clean, even, well-formed surface. As soon as the centering is removed, it should be examined, and, if bent or dented, straightened, and the surface thoroughly brushed at once and given a coat of oil or soft soap, so that they are ready for use again and not left for the particles of concrete to harden on the surface, after which it would take five times as much trouble and labor to put them into working order.

"We do not rely on the girder and cross-beam boxes

to carry the dead load of the concrete, but rely on adjustable posts to support them in the middle until the concrete is thoroughly hard. The girder box form is so arranged that the post need not be disturbed while the box is being removed, so that there is no danger of accident or failure taking place while tearing down."

EXPANSION AND CONTRACTION

Prevention of Cracks.—Change of temperature is a cause of innumerable secondary stresses in many structures. In such work as tanks and long walls, in which cracks are inadmissible, absolute continuity of reinforcement is necessary.

In buildings of relatively small dimensions as to ground area, no expansion, or rather contraction, joints are necessary, especially in the upper stories. In long buildings, some joints may be advisable in order to do away with the heavy tensile secondary stresses which must sometimes exist and which show themselves by cracks, frequently at unsightly and dangerous places. In small buildings, the use of numerous distributing rods through the floors at right angles to the regular carrying rods will usually be sufficient, so far as the floors themselves are concerned. Around window and door openings, special reinforcement should always be provided to prevent the formation of cracks, which often start at all four corners and extend for short distances into the walls.

Roofs are subject to extraordinary changes of temperature in their several parts, and need

the greatest of care in the design of their reinforcement, especially when the slabs are treated as the flanges of long-span roof-girders.

In larger buildings, clean-cut joints may be installed and can best be placed at the centers of panels by providing cantilever beams or girders half a span in length on each side. Such joints should always be covered with an elastic waterproof coating to shed the water falling on the floors in case of fire.

FACTORY VS. FIELD-MADE REINFORCEMENT

In regard to the relative merits of factory-made reinforced concrete structural work and field-made work, Mr. Charles D. Watson says:

"A careful analysis of the present conditions under which reinforced concrete is constructed cannot help but lead one to the conclusion that present methods are still crude and unscientific; and like the history of all such developments, we must abandon the use of hand-made materials, which are subject to faults due to human errors, and adopt the machine-made. If so, the final outcome must be the use of factory-made reinforced concrete. Factory-made concrete has obviously every advantage over field-made, except in the matter of continuity of members and the cost of transportation for long distances. As to continuity—with the present development toward the shop fabrication of reinforcement and rigid connections of members, it is doubtful if the monolithic method of construction really has so much advantage in this particular. Certainly, more rigidity can be obtained than in a structural steel frame. Furthermore, in the majority of cases it is impossible to get a truly monolithic struc-

ture by present field methods, since the cost of placing concrete continuously makes it practically prohibitive. There are other positive disadvantages in monolithic designs, due to the absence of expansion joints, the differential expansion of members of different sections, and the consequent thermal stresses set up in such structures, which are beyond the engineer's power to calculate.

"As regards transportation of factory separately moulded members, there can be little doubt that in the larger centers of population the cost of transporting the finished product is overcome by the many other advantages of the factory-made members, such as: first, elimination of forms; second, concrete of much greater strength and consequently of much smaller volume to carry equal loads; third, the use of more economical sections; fourth, the economy of shop methods of handling and mixing the materials; fifth, the greater speed of erection; sixth, certainty of results on account of mechanical methods of fabrication of the reinforcement and casting of members; seventh, the opportunity to test same before subjection of load; eighth, ease of alterations; ninth, absence of accidents during erection; and tenth, high-grade finish made possible by better forms.

"First, as to saving of field forms: It is obvious that any system of concrete construction which will eliminate the present expense of the forms required in field work would be of the greatest advantage. The moulding of concrete in this way is not only expensive, but fraught with great danger, inasmuch as the members are completely covered until the forms are removed, which obscures defects and prevents inspection.

"Second, as to the quality of concrete and section of members: Recent experiments have demonstrated the enormous variation which may occur in the strength of concrete due to its quality. The profession is now giving this question of high-grade material considerable prominence. We constantly hear references to the great

strength of concrete with the common expression 'as hard as rock'; but the real conditions under which it is used for structural purposes are such that we are compelled to use working values in compression, which are about half of what we use for soft timber. The result is one of the greatest objections to concrete construction; that is, to get sufficient strength to carry loads, we are compelled to erect such massive beams and columns that our buildings become architectural monstrosities, besides being uneconomical on account of the space wasted. In entering a concrete building of considerable height and with long spans designed for heavy loads, the massiveness of the beams and columns gives one the impression of clumsiness rather than stability. Development of the science is gradually eliminating this defect; but the primary reason still remains, and can be solved only by the use of a higher-grade material which will have greater strength, so that a smaller section may be used.

"There can be no doubt that the highest quality of concrete can be made only in a factory where every condition as to quality of material, methods of manufacture, and seasoning can be carefully studied and regulated. Men expert in each division of the process of manufacture can supervise all operations, and, by the use of mechanical equipments which it is impossible to establish in the field, will be enabled to work at the highest point of efficiency and economy.

"Next in importance to the quality of concrete is the advantage of economical sections into which it may be moulded under shop methods. Every engineer knows that in a rectangular beam there is great waste of material as regards actual areas under stress. For this reason, steel is rolled into what are commonly known as structural shapes; but even in the manufacture of steel, mechanical difficulties prevent the rolling of truly economical sections. Concrete, being a plastic material, presents no such difficulties; and when factory-made,

practically any section can be cast in permanent metal moulds by proper appliances for filling same. Also the distribution of reinforcing steel can be developed to a much higher degree, and the position of the steel in the member made absolutely certain. Many attempts have been made in the field to cast concrete members of more economical shape, and numerous systems have been devised, consisting mostly of the use of hollow tile or similar material for coring or reducing the sections. But under field conditions the saving is but slight, as the hollow cores must be left in the work, and the whole temporarily supported until the concrete is sufficiently hardened to enable it to resist loads.

"As to the economy of shop methods of manufacture over field methods, this has so often been demonstrated in all lines of industry that any discussion is unnecessary. A plant for such a purpose should be located in the larger centers of population and at or near some source of supply of raw material. Facilities for handling raw materials at a minimum cost, and for handling, casting, and finishing the completed products, can be permanently installed; also crushing, screening, and mixing machinery that will automatically regulate the size and proportions of materials which will not only produce uniform and high-quality results, but at a minimum of expense.

"With a proper arrangement of plant it certainly is not unreasonable to expect that structural concrete sections can be manufactured in a factory, transported and erected in the field at a cost per cubic yard not much in excess of what it now costs to erect concrete building blocks, plus the cost of steel reinforcement and the fabrication of same. This in round figures should not exceed fifteen dollars per cubic yard actual measurement. Bearing in mind that these factory-made sections can be made with a saving of from 33 to 50 per cent of the volume necessary to produce the same results by field methods,

due to the fact already stated that the concrete is twice as strong and of more economical section, its cost would be not over ten dollars per cubic yard, as compared with the actual contents of present field-made monolithic construction.

"The development of the unit-system of structural concrete is sure to result in a most productive field for the manufacturer of cement products, and should grow into a large and important industry. The greater speed at which buildings constructed of factory-made units may be erected, the comparative ease with which alterations may be made, and the absolute certainty of results due to the fact that members can be tested, are quite apparent advantages. There seems to be little doubt that the majority of failures of monolithic construction are due to the premature removal of forms. It is uneconomical to leave these forms in place more than three weeks at the most, and the strength of concrete at this age is seldom more than half of what it attains in two months. The use of factory-made materials will allow full loads to be imposed immediately after erection, and as they require no temporary supports all danger of failures is eliminated.

"From an architectural view, field-moulded concrete is objectionable, not only on account of the enormous size of its members, but on account of the difficulty of getting a high-grade finish; factory-made materials can be cast in smaller sections and in forms, or in sand moulds, which leave a high-grade and very satisfactory finish. Members can even be designed and moulded with a view to architectural appearance, combining both the structural and architectural features of the building without the expense of additional work of finishing and ornamentation.

"As already stated, the only possible disadvantages that the unit-system might have are those of transportation of heavy members for long distances from the factory, and the absence of continuity between members.

"The economies of shop manufacture and erection, combined with the fact that much less volume of concrete is required to produce the same results on account of more economical sections and higher quality of material, will more than overcome the difference in the cost of transportation.

"As to the advantage of continuity of members and rigidity obtained by monolithic construction, here, without doubt, lies the real problem in the development of the unit-system. However, the problem admits of ready solution by proper care and ingenuity in the fabrication of reinforcement. The members can be made with projecting connections, which can be rigidly attached to each other in the field similar to the manner in which structural steel is erected, and these connections can afterwards be fireproofed with a small amount of field concrete.

"The bolting of connections can be substituted for the expense of riveting, as is required in structural steel. For buildings of few stories, the combination of the adhesion of mortar and the use of projecting dowels is all that is necessary. Such construction requires slightly more steel than is ordinarily used in concrete construction, but the expense of this is more than overcome by other economies.

"In cities where the cost of structural steel is not excessive it has been found that a very economical, rapid, safe, and efficient mode of construction is to erect a light structural steel frame, which is designed for dead load only, and is afterwards fireproofed by supporting forms on the members and filling in around them with concrete, the steel being designed just within its elastic limit, and the additional strength required to resist live load and provide for a factor of safety being supplied by the concrete. In the specifications of one designer, this form of construction is referred to as 'reinforced steel construction.' Certainly this form of construction could

be made much more economical if the concrete fireproofing were put on at the factory, as it would entirely eliminate the cost of field forms, and enable the designer to take advantage of the fact that the member has the additional strength of the concrete added, enabling him him to reduce the amount of steel. The only additional cost of erecting a reinforced steel frame of this nature over that of a regular structural steel frame designed for both dead and live load, would be the additional cost of transporting and erecting the heavier members. However, recent calculations made on a four-story apartment building showed that this form of construction could be carried out using the customary loads for this style of building, and spans of sixteen feet, in which no member weighed more than one ton, the actual weight of the members being a trifle over twice what the weight would be if a structural steel frame were used and designed for both dead and live loads. The saving in forms, the greater speed of erection, the economy of design in this form of construction, certainly warrant its careful consideration by designing engineers."

SPECIFICATIONS FOR REINFORCED CONCRETE

As an example of the manner in which a set of specifications should be drawn up for reinforced concrete work, the Trussed Concrete Steel Company furnish the following form:

General—

It is the intention of these specifications to include all that is considered best in theory and practice. Special attention must be given in this construction to the quality of labor, material, and character of workmanship.

Bidders must be thoroughly experienced in this class of work, and must have carried through successfully building operations of large and responsible character.

Parties submitting proposals must furnish drawings, indicating their method of calculation, the arrangement and nature of the steel reinforcement for the various structural members indicated; and no proposition will be considered without such calculations and drawings. It is understood furthermore that no system of reinforced concrete construction will be considered which has not been approved by the building departments of all the principal cities of the United States which have studied reinforced concrete and have embodied conditions governing its use in their Building Code—namely, New York, Philadelphia, Washington, Cleveland, and St. Louis.

Dimensions of beams, columns, slabs, and other structures indicated on drawings shall be considered a minimum.

All materials rejected for this work must be immediately removed from the vicinity. Samples of all materials must be submitted and approved by the architect before same are used.

Cement—

1. All cement shall be tested.
2. The contractor shall notify the engineer-in-charge as soon as each car of cement is placed, so that the samples may be taken therefrom without delay.
3. In order to allow ample time for inspecting and testing, the cement must be stored in a suitable weather-tight building, having the floor properly blocked or raised from the ground.
4. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each carload.
5. Every facility shall be provided by the Contractor and a period of at least fourteen days allowed for the inspection and necessary tests.
6. Cement shall be delivered in suitable bags with the brand and name of manufacturer plainly marked thereon.
7. Cement failing to meet the seven-day require-

ments, may be held awaiting the results of the twenty-eight days tests before rejection.

8. All tests shall be made in accordance with the methods proposed by the Committee of Uniform Tests of Cement of the American Society for Testing Materials, presented to the Society, January 21, 1903, and amended January 20, 1904, with all subsequent amendments thereto.

9. The acceptance or rejection shall be based on the following requirements:

I. The term "Portland Cement" is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than three per cent has been made subsequent to calcination.

II. The specific gravity of the cement thoroughly dried at 100 degrees C. (212 degrees F.) shall be not less than 3.10.

III. All of the cement shall pass through a No. 50 sieve. It shall leave by weight a residue of not more than seven per cent on a No. 100 sieve and not more than twenty-two (22) per cent on a No. 200 sieve.

IV. It shall develop initial set in not less than forty minutes, but must develop hard or final set in not less than two hours, nor more than ten hours.

V. The minimum requirements for tensile strength for briquettes, one inch square in section, shall be as given below and shall show no retrogression in strength within the periods specified.

Neat Cement

Age—24 hours..... 150 lbs
in moist air

Age— 7 days..... 450 lbs.
1 day in moist air, 6 days in water

Age—28 days..... 650 lbs.
1 day in moist air, 27 days in water

One Part Cement, Three Parts Standard Sand

Age— 7 days..... 160 lbs.
1 day in moist air, 6 days in water

Age—28 days..... 250 lbs.
1 day in moist air, 27 days in water.

VI. Pats of neat cement about 3 inches in diameter, one-half inch thick at the center, and tapering to a thin edge shall be kept in moist air for twenty-four hours.

(a) A pat is then kept in air at normal temperature, and observed at intervals for at least twenty-eight days.

(b) Another pat is kept in water maintained as near 70 degrees F. as practicable, and observed at intervals for at least twenty-eight days.

(c) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

VII. These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

VIII. The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than three per cent of magnesia (Mg O).

Only clean sand shall be used. It shall be coarse and sharp, with grains of various sizes, and also contain the smallest possible percentage of voids. Sand having over 3 per cent loam shall be rejected.

The aggregate shall be composed of broken stone or gravel. The broken stone shall be of a hard, close-grained quality, free from dust, and crushed so that its largest dimension shall pass through a ring one inch in diameter.

Gravel should be free from dirt, and should be in size ranging from that of a pea to an inch. Disintegrated stone or broken stone containing mica shall be rejected.

All concrete for slabs and beams shall be proportioned of one part Portland Cement, two parts of sand, and four parts of broken stone or gravel.

All concrete for columns shall be proportioned of one part Portland cement, 1½ parts of sand, and 2 parts of broken stone or gravel.

All concrete shall be machine mixed, using either a batch or a continuous mixer of an approved design. Plenty of clean water should be used, so that the resultant mixture has the consistency of what may be known as a "wet" mixture. All materials shall be first thoroughly mixed dry, after which the proper amount of water is added, and the mixing continued until the concrete is uniform. A competent foreman must be in constant attendance at the mixer, to give his approval of every batch which leaves the machine.

No reinforcing steel shall be considered that does not provide for shearing stresses as well as direct tension. These resisting members must be inclined to an angle of 45 degrees, pointing up and towards the supports of the structure. Shear members shall be rigidly attached to the main tension member. Sufficient steel shall be placed so that the concrete will be obliged to resist only direct compression, and shearing stress up to 50 pounds per square inch. No steel shall have, at any point, less than 1 inch of concrete covering. Steel bars shall not be painted. A slight film of rust will not be objectionable upon same, but any bar on which decided rust scales have formed shall be rejected. In no case shall steel of higher elastic limit than 45,000 lbs. be considered. The same shall have a tensile strength of from 60,000 to 70,000 lbs. per square inch, with an elongation of not less than 20 per cent in 8 inches. A bar should bend when cold, around its own diameter, through an angle of 180 degrees, and close down upon itself without cracking.

Steel shall be placed in exact accordance with detail drawings.

Concrete shall be placed as rapidly as possible after mixing, and shall be thoroughly puddled immediately thereafter.

When concreting is once commenced, it should be carried on vigorously to completion, if possible. If concreting must be stopped before an entire floor is completed, the stop shall be made in the center of beams and center of floor slabs. The plane where concrete work is stopped must be at right angles to the direction of the beam or slab. In no event shall work be terminated in beams or floor slabs where future shearing action becomes great, as at their ends or directly under a heavily concentrated load.

In freezing weather, special precaution must be taken to protect the exposed surfaces.

Concrete shall be placed in freezing weather, only when same cannot possibly be prevented; and then especial precautions must be used to cover the work at once with at least five or six inches of sawdust or manure. The forms for such work should be left in place at least three weeks longer than customary, and under no circumstances shall they be removed unless the concrete has thoroughly set and the frost entirely disappeared. Concrete for slabs shall be laid immediately after pouring the beams. Under no circumstances shall the concrete in the beam boxes be permitted to set before the concrete for the slab is poured.

It is by all means preferable to avoid concrete work in freezing weather. Concrete laid under these conditions is treacherous at its best.

The centering must be true and rigid and properly braced, and of sufficient strength to carry easily the dead weight of the construction as a liquid, without deflection.

All joints must be fairly tight so as to prevent leakage of liquid masses. The design of the centering should be such that the sides of the beams can be taken down first, then the slab centering complete. Centering should never be removed until the concrete has thoroughly set, and has aged to give it sufficient strength to carry its own weight besides whatever live load is liable to come on

the work during the course of construction. In no event shall the falsework be removed until approval is given by the architect or engineer-in-charge. Beams shall remain supported for at least two weeks after all other falsework has been removed. Columns shall not be given their full loading in less than five weeks after concreting.

After the forms are removed, any small cavities or openings in the concrete shall be neatly filled with mortar if necessary. In order to obtain a very smooth finish, wash with a thin grout of mortar of the consistency of whitewash, mixed in a proportion of one part cement and three parts sand. This wash should be applied with a brush.

Floors shall be tested after the centering has been removed one month, to a uniformly distributed load equal to twice the safe live load. With this load there should not be a deflection exceeding 1-400th part of the span, and the floor should return to its normal position after the removal of the load.

The following stresses based on figuring full live and dead loads shall be used in the design of reinforced concrete work:

For hooped concrete columns, 750 lbs. per sq. in. of concrete.

For latticed columns, 500 lbs. per sq. in.

For shearing stresses in concrete and adhesion of concrete to steel, 50 lbs. per sq. in.

Extreme fiber stress in compression for slab, beams, and girders, 750 lbs. per sq. in.

Tensile stress in steel, 16,000 lbs. per sq. in.

The ratio of moduli of elasticity of concrete and steel to be 1 to 15.

The tensile strength of concrete shall not be considered.

When slab and beams are built continuous over their supports, the bending moment may be taken at 1-10 Wl. In cases of square floor panels, floor supported on all four sides and built continuous over supports, the bending

moment may be taken at 1-20 Wl. In all such cases sufficient reinforcement must be provided at the top of the slab to take care of the regular bending moment at the supports.

The cement finish for floors shall be proportioned not leaner than 1 to 2, using in all cases a specially sharp, clean, and gritty sand. It shall be troweled to a thoroughly smooth and even surface, and shall be cut in squares of not more than eight feet.

Cement finish when applied to a concrete base must be laid at the same time as the base, and shall not be less than ½ inch in thickness. When applied to tile surface, it shall be not less than two inches in thickness, special care being taken to clean the tile and secure a thorough bond between it and the cement.

Since the success of the structure depends so largely upon the steel and the manner of placing same, we quote an opinion by Mr. H. F. Porter, which he considers should be embodied in sets of specifications.

"All steel to be of best quality, made from original billets and in strict accordance with the regulation standard for structural steel. It shall be free from all scale and laminations and defects endangering the strength of the material. It shall also be free from all dirt, oil, and rust pocks, although a slight film of rust is permissible. The ultimate strength shall not be less than four times the safe unit-stress used, and the elastic limit less than two and a-half times. All reinforcement to be properly fabricated and supported in place, so that all parts shall remain in true position and alignment until locked in the setting concrete. All tensile stresses, theoretical and practical, that may occur in the structure and any of its parts, shall be fully and properly provided for by steel reinforcement. In general, the reinforcement shall run as continuously as possible throughout the struc-

ture, and full development of every piece provided by suitable end-anchorage and lapping. Diagonal tensions in beams to be cared for completely by diagonal reinforcement, either a part of or rigidly attached to the main reinforcement. In the slabs, these stresses and the negative stresses to be cared for simultaneously with the positive stresses, by elevating a sufficient number of the bars across the supports, providing in effect a catenary curve reinforcement.

"Vertical tension to be cared for by vertical loops of steel, passing around the lower horizontal bars and extending well up into the compression flange, in which they shall be well anchored. These loops or stirrups shall be spaced not farther apart than the effective depth of the member and at progressively diminishing intervals towards the supports. In case of T-beams, vertical stirrups are necessary to guard against possible separation of the rib from the slab along the plane of junction, and to insure the full and proper development of the T-action. All placing of reinforcement shall be done before undertaking to concrete, so that in amount and position it may be easily and fully checked before any concrete is deposited; conversely, no steel shall be left to be placed while the concreting is in progress. In slabs and walls, if bars are used, cross or shrinkage bars shall be provided at proper intervals, the intersections securely wired or clamped, and the bars properly and securely spaced and supported in position, prior to any concreting."

Official Report on Reinforced Concrete

As an official pronouncement representing a summary of approved practice in reinforced concrete work, the following extracts from the report of the Committee on Reinforced Concrete of the National Association of Cement Users will be found of great interest and practical value:

2. **Uses.** Concrete, plain and reinforced, is recognized as an established material for construction. Because of its fire-resisting qualities, strength in compression, and relatively low cost, concrete is adapted not only to structures where stresses are principally compressive, such as foundations, dams, retaining walls and other walls, piers, abutments, short columns and arches; but with the use of metal reinforcement properly placed, it is also available for a variety of structures and structural forms where both compression and tension exist, as in beams and slabs.

3. **Resistance to External Agencies—Fire Resistance.** Concrete is incombustible and resists the action of ordinary fires, so that it may be safely used for fireproofing purposes. The thickness of the protective coating required depends upon the probable duration of a fire which is likely to occur in a structure. For ordinary conditions it is recommended that the metal in girders and columns be protected by a minimum of 2 inches of concrete, that the metal in beams be protected by a minimum of 1½ inches of concrete, and that the metal in floor slabs be protected by a minimum of 1 inch of concrete. In monolithic concrete columns the concrete to a depth of 1½ inches may be considered as a protective covering and not included in the effective section when computing the strength.

4. **Water-tightness.** When proportioned to attain greatest density, not leaner than one part cement to two parts fine aggregate, to four parts coarse aggregate, and mixed to a rather wet consistency, concrete is impervious under ordinary conditions. Long walls to resist water pressure must be effectively reinforced to prevent cracks due to temperature contraction or shrinkage, or must be waterproofed by asphaltic or similar preparation, or the length may be broken by vertical construction joints sealed by metal flashing.

5. **Corrosion of Metal Reinforcement.** Steel embedded in good, dense concrete will not corrode under ordinary conditions, whether located above or below fresh or sea water level. On the other hand, if concrete is porous, it may permit moisture to penetrate and corrode the metal.

6. **Sea Water.** To best resist sea water, concrete must be proportioned to secure maximum density and mixed thoroughly to obtain impervious concrete.

7. **Acids.** Concrete of first-class quality thoroughly hardened is affected appreciably only by strong acids which seriously injure other materials. A substance like manure, because of the acid in its composition is injurious to green concrete, but after the concrete has thoroughly hardened it satisfactorily resists such action.

8. **Oils.** When concrete is properly made and the surface carefully finished and hardened, it resists the action of such oils as petroleum and ordinary engine oils. Certain oils which contain fatty acids appear to produce injurious effects.

9. **Alkalis.** In the arid regions, alkaline ground water in some cases has been known to injure concrete and most other structural materials. For use under such conditions, concrete should be especially rich, dense, and impervious.

10. **Responsibility and Supervision.** The users of cement will recognize the great difference, in both design and construction, between plain concrete work such as sidewalks, roads, foundations, heavy mass work, etc.,

and reinforced concrete structures. Plain concrete serves the requirements admirably for work where tensile stresses do not occur to any extent. In reinforced concrete structures, steel must be added to the concrete to make a safe structure; and the proper sizes, dimensions, and arrangement of concrete and steel to obtain safety, strength, and durability, require the knowledge and experience of the engineer. Many of our failures in reinforced concrete construction are the results of improper or inadequate design, and many others are due to incompetent supervision.

11 It is therefore strongly recommended that all structures to be built of reinforced concrete shall be designed by experienced reinforced concrete engineers, and that the drawings to be furnished to the builder shall show clearly and in detail the sizes and dimensions of all parts of the structure, the lengths of all steel reinforcement and its exact position with respect to the concrete members, and that these drawings shall be accompanied by specifications giving the quality of the materials to be used, the proportions of the concrete, and the character of the workmanship.

12. It is also strongly recommended that the character of the supervision given to reinforced concrete structures be improved. Such supervision as is customary in the building trades is not sufficient to attain either successful or economical construction in reinforced concrete.

13. All reinforced concrete work should be under the constant direction of experienced reinforced concrete superintendents—preferably men having a knowledge of engineering.

14. **Cement.** Only Portland cement is suitable for reinforced concrete construction, or for any construction that will be subject to shocks or vibrations or stresses other than direct compression.

15. The cement should meet the requirement of the

Standard Specifications for cement as adopted by the American Society for Testing Materials.

16. **Fine Aggregates.** Fine aggregate consists of sand, crushed stone, or gravel screenings passing when dry a screen having ¼-inch diameter holes or a screen having four meshes to the linear inch. It should be preferably of siliceous material, clean, coarse, and free from vegetable loam and other deleterious matter.

17. It is impossible to determine positively the quality of a sand by inspection. Frequently a sand containing a very small percentage of silt may have its grains coated with organic or other matter so as dangerously to retard the setting of the concrete; consequently the testing of the sand is fully as important as the testing of the cement.

18. Mortars composed of one part Portland cement and three parts fine aggregate by weight, when made into briquettes, should show a tensile strength of at least 70 per cent of the strength of 1:3 mortar of the same consistency made with the same cement and standard Ottawa sand. To avoid the removal of any coating on the grains which may affect the strength, bank sands should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture may be determined upon a separate sample for correcting weight. From 10 to 40 per cent more water may be required in mixing bank or artificial sands than for standard Ottawa sand, to produce the same consistency.

19. The relative strength of mortars from different sands is largely affected by the size of the grains. A coarse sand gives a stronger mortar than a fine one, and generally a gradation of grains from fine to coarse is advantageous. If a sand is so fine that more than 10 per cent of the total dry weight passes a No. 100 sieve, or if more than 35 per cent of the total dry weight passes a sieve having 50 meshes per linear inch, it should be rejected or used with a large excess of cement.

20. For the purpose of comparing the quality of

different sands a test of the mechanical analysis or granulometric composition is recommended, although this should not be substituted for the strength test. The percentages of the total weight passing each sieve should be recorded. For this test the following sieves are recommended:*

0.250 inch diameter holes.†
No. 8 mesh, holes 0.0955 inch width, No. 23 wire.
No. 20 " " 0.0335 " " No. 28 "
No. 50 " " 0.0110 " " No. 35 "
No. 100 " " 0.0055 " " No. 40 "

21. The effect of mechanical analysis or granulometric composition upon the strength of mortar is set forth in Table I. By this table the relative strength of different sands may be approximately estimated.

TABLE I

Tests by New York Board of Water Supply of 1:3 Mortar Made With Sands of Different Mechanical Analysis.

Percentages Passing Sieves				Tensile Test		Compression Test	
				7	90	7	90
No. 4	No. 8	No. 50	No. 100	days	days	days	days
100	70	12	5	213	613	2690	5640
100	86	21	6	263	412	1915	4660
100	99	26	2	177	325	905	2170
100	97	28	6	178	282	1070	1500
100	94	44	12	139	228	905	1130
100	100	52	14	122	170	275	810
100	100	94	48	80	149	330	490

22. **Coarse Aggregates.** Coarse aggregate consists of inert material such as crushed stone, or gravel, which

* Sheet brass perforated with round holes passes the material more quickly than square holes. Round holes corresponding to sieves No. 8, 20, and 50 respectively are approximately 0.125, 0.050, 0.020 inch diameter.

† A No. 4 sieve, having 4 meshes per linear inch, passes approximately the same size grains as a sieve with 0.25 inch diameter holes.

is retained on a screen having ¼-inch diameter holes. The particles should be clean, hard, durable, and free from all deleterious material. Aggregates containing soft, flat, or elongated particles, should be excluded from important structures. A gradation of sizes of the particles is generally advantageous.

23. The maximum size of the coarse aggregate should be such that it will not separate from the mortar in laying, and will not prevent the concrete fully surrounding the reinforcement or filling all parts of the forms. Where concrete is used in mass, the size of the coarse aggregate may be such as to pass a 3-inch ring. For reinforced concrete, a size to pass a 1-inch ring or a smaller size may be used.

24. Cinder concrete is not suitable for reinforced concrete structures, and may be safely used only in mass for very light loads or for fireproofing.

25. Where cinder concrete is permissible, the cinders used as the coarse aggregate should be composed of hard, clean, vitreous clinker, free from sulphides, unburned coal, or ashes.

26. **Water.** The water used in mixing concrete should be free from oil, acid, strong alkalis, or vegetable matter.

27. **Metal Reinforcement.** The Committee recommends that mild steel such as fills the specifications for structural steel of the American Railway Engineering and Maintenance of Way Association is a suitable material.

28. If steel of higher elastic limit is used, it must be of first-class quality and subjected to special tests even if used at the same working stress as mild steel. It should be required to pass the following test:

29. Test specimens for bending shall be bent cold under the following conditions without fracture on the outside of the bent portion:

Around twice their own diameter: 1 in. diameter,

80 degrees; ¾ in. diameter, 90 degrees; ½ in. diameter, 110 degrees.

Around their own diameter: ¼ in. diameter, 130 degrees; $\frac{3}{16}$ in. diameter, 140 degrees; ⅛ in. diameter or less, 180 degrees.

The reinforcement should be free from rust, scale, or coatings of any character which would tend to reduce or destroy the bond.

30. **Proportions.** The materials to be used in concrete should be carefully selected, of uniform quality, and proportioned with a view to securing as nearly as possible a maximum density.

31. The unit of measure should be the barrel, which should be taken as containing 3.8 cubic feet. Four bags containing 94 pounds of cement each should be considered the equivalent of one barrel. Fine and coarse aggregate should be measured separately as loosely thrown into the measuring receptacle.

32. If the coarse aggregate contains sand or other fine material, that which passes a sieve with ¼-inch round holes should be considered as sand in measuring proportions. In general, the concrete on the work should contain enough and only enough mortar to cover all particles of stone and fill the voids without an appreciable excess of mortar.

33. The proportions of cement to sand and stone should be chosen after a very careful study of the local conditions and the available materials. For small and unimportant structures, the following list is presented to be used as a rough guide to the selection of proportions for different classes of work. The relative proportions of fine to coarse aggregate may be varied to suit the materials:

(a) **A rich mixture,** for columns and other structural parts subjected to high stresses or requiring exceptional water-tightness: Proportions 1:1½:3.

(b) **A standard mixture,** for reinforced floors, beams,

and columns, for arches, for reinforced engine or machine foundations subject to vibrations, for tanks, sewers, conduits, and other water-tight work: Proportions 1:2:4.

(c) **A Medium mixture,** for ordinary machine foundations, retaining walls, abutments, piers, thin foundation walls, building walls, ordinary floors, sidewalks, and sewers with heavy walls: Proportions 1:2½:5.

(d) **A lean mixture,** for unimportant work in masses, for heavy walls, for large foundations supporting a stationary load, and for backing for stone masonry: Proportions 1:3:6.

34. **Mixing of Concrete.** Methods should be devised to make always positive the proper proportioning and therefore the accurate measuring of the concrete materials, including water. Accurate measurements are of the greatest importance.

35. The concrete materials should be mixed until the cement is uniformly distributed throughout the mass, and the concrete therefore uniform in color and homogeneous. Sufficient water must be added during the mixing to produce a concrete that will flow when agitated, but not so wet as to permit a separation of the materials in transferring from mixer to the work. Mixing by machine should always be preferred, since the most thorough and uniform consistency can thus be obtained.

36. The type of mixer should be used which will insure thorough and accurate proportioning of the materials throughout the mass.

37. Where hand-mixing is necessary, the mixing should be done on a water-tight platform, and special precautions taken to turn the materials until they are homogeneous in appearance and color. Concrete that has started to set or has been out of the mixer more than thirty minutes, should not be used. Re-tempering of either mortar or concrete which has partially hardened should not be permitted.

38. Concrete for reinforced concrete structures should

not be mixed or deposited at a freezing temperature, unless special precautions are taken to avoid the use of materials containing frost, and to provide means for preventing the concrete from freezing after being placed in position and until it has thoroughly hardened.

39. **Placing Concrete.** Concrete must be placed in the work immediately after mixing, and deposited and rammed or agitated by suitable tools in such a manner as to produce thoroughly compact concrete of maximum density. No concrete should be placed until the reinforcing steel has been placed and firmly secured by wiring or other methods to prevent displacement. Concrete should be frequently wet for several days to prevent too rapid drying out.

40. Concrete should not be placed in water, unless unavoidable. Where concrete must be placed under water, unusual care must be taken to prevent the cement from being floated away. This usually can be accomplished in still water by placing the concrete through a large pipe or tube, or, in large work, by means of a bottom-dump concrete basket. Before placing concrete, all shavings and debris of every nature must be removed, and the concrete surface thoroughly cleaned and drenched with water.

41. **Forms.** Forms should be substantially built and secured to prevent movement or deflection during concreting, and tight to prevent leakage of mortar.

42. Before the removal of forms, the concrete should be carefully inspected and its strength ascertained. Much care should be given to this portion of the work, which is fraught with danger under incompetent direction. No exact time for the removal of forms can be safely prescribed, because of the varying character of the work, the variations in the setting of different cements, and the influence of atmospheric conditions.

43. **Joints.** Temperature changes and shrinkage during setting necessitate joints at frequent intervals or

else effective reinforcement, depending upon the range in temperature and the design of the structure.

44. In massive work, such as retaining walls, abutments, etc., built without reinforcement, joints should be provided approximately every 30 to 50 feet throughout the length of the structure.

45. Girders should never be constructed over freshly formed columns without allowing a period of at least two hours to elapse to permit settlement in the columns. Before resuming work the top of the column should be thoroughly cleansed of foreign matter and laitance.

46. To obtain tight joints between new and old concrete, the old surface should be roughened, thoroughly cleaned of all foreign material and laitance or scum, drenched, and slushed with neat cement or with a mortar not leaner than one part Portland cement to two parts fine aggregate.

47. Joints in reinforced concrete should be avoided when possible by casting the entire structure at one operation. In building construction, joints may be made in the columns flush with the lower side of the girders; and joints in members of a floor system in general should be made at or near the center of the span. In all cases joints should be at right angles to their surfaces.

48. **Design of Reinforced Concrete.** By the use of metal reinforcement to resist the principal tensile stresses, concrete becomes available for general use in a great variety of structures and structural forms. This combination of concrete and steel is particularly advantageous in the beam where both compression and tension exist; it is also advantageous in the column where the main stresses are compressive, but where cross-bending may exist. The theory of design will therefore relate mainly to the analysis of beams and columns.

49. **Loads.** The loads or forces to be resisted consist of:

A

BRIDGE AT YORKTOWN, INDIANA.

Span of waterway, 95 feet.

B

HIGHWAY ARCH BRIDGE AT OSHAWA, ONTARIO.

PLATE 3—CEMENT CONSTRUCTION.

(a) **The dead load,** which includes the weight of the structure and fixed loads and forces.

(b) **The live load,** or the loads and forces which are variable. The dynamic effect of the live load will often require consideration. Any allowance for the dynamic effect is preferably taken into account by adding the desired amount to the live load or to the live-load stresses. The working stresses hereinafter recommended are intended to apply to the equivalent static stresses so determined.

50. In the case of high buildings, the live load on columns may be reduced in accordance with the usual practice.

51. **Lengths of Beams and Columns.** The span length for beams and slabs shall be taken as the distance from center to center of supports, but shall not be taken to exceed the clear span plus the depth of beam or slab. Brackets shall not be considered as reducing the clear span in the sense here intended.

52. The length of columns shall be taken as the maximum unsupported length.

54. **Working Stresses.** The following working stresses are recommended for static loads. Proper allowances for vibration and impact are to be added to live loads where necessary to produce an equivalent static load before applying the unit-stresses in proportioning parts.

55. In selecting the permissible working stress to be allowed on concrete, we should be guided by the working stresses usually allowed for other materials of construction, so that all structures of the same class, but composed of different materials, may have approximately the same degree of safety.

56. The stresses for concrete are proposed for concrete composed of one part Portland cement and six parts aggregate, capable of developing an average compressive strength of 2,000 pounds per square inch at 28

days, when tested in cylinders 8 inches in diameter and 16 inches long, under laboratory conditions of manufacture and storage, using the same consistency as is used in the field. In considering the factors recommended with relation to this strength, it is to be borne in mind that the strength at 28 days is by no means the ultimate which will be developed at a longer period, and therefore they do not correspond with the real factor of safety. On concretes in which the material of the aggregate is inferior, all stresses should be proportionately reduced, and similar reduction should be made when leaner mixes are to be employed. On the other hand, if, with the best quality of aggregates, the richness is increased, an increase may be made in all working stresses proportional to the increase in compressive strength at 28 days, but this increase shall not exceed 25 per cent.

57. **Bearing.*** For compression on surface of concrete larger than loaded area, 32.5 per cent of compressive strength at 28 days, or 650 pounds per square inch on 2,000-pound concrete.

58. **Plain columns.** Plain columns or piers whose length does not exceed twelve diameters, 22½ per cent of compressive strength at 28 days, or 450 pounds per square inch on 2,000-pound concrete.

59. **Reinforced Columns.** See paragraphs 96 to 104, below, on "Columns."

60. **Compression in Extreme Fiber.** For extreme fiber stress of beams calculated for constant modulus of elasticity, 32.5 per cent of the compressive strength at 28 days, or 650 pounds per square inch for 2,000-pound concrete.

61. Adjacent to the support of continuous beams, stresses 15 per cent greater may be allowed.

62. **Shear.** Pure shearing stresses uncombined with compression or tension, 6 per cent of compressive strength

* For beams and girders built into pockets in concrete walls, the lower compressive stress of 450 pounds per square inch should not be exceeded.

at 28 days, or 120 pounds per square inch for 2,000-pound concrete.

63. **Diagonal Tension.** In beams where diagonal tension is taken by concrete, the vertical shearing stresses should not exceed 2 per cent of compressive strength at 28 days, or 40 pounds per square inch for 2,000-pound concrete. See also paragraph 88, below, on "Shear and Diagonal Tension."

64. **Bond for Plain Bars.** Bonding stress between concrete and plain reinforcing bars, 4 per cent of compressive strength at 28 days, or 80 pounds per square inch for 2,000-pound concrete.

For drawn wire, 2 per cent, or 40 pounds on 2,000-pound concrete.

65. **Bond for Deformed Bars.** Bonding stress between concrete and deformed bars may be assumed to vary with the character of the bar from 5 per cent to 7½ per cent of the compressive strength of the concrete at 28 days, or from 100 to 150 pounds per square inch for 2,000-pound concrete.

66. **Reinforcement.** The tensile stress in steel should not exceed 16,000 pounds per square inch. The compressive stress in reinforcing steel should not exceed 16,000 pounds per square inch, or fifteen times the working compressive stress in the concrete.

67. **Modulus of Elasticity.** It is recommended that in all computations the modulus be assumed as $^1/_{15}$ that of steel.

68. **Standard Notation.** The following notation is recommended by the Joint Committee:

M=Moment of resistance, or bending moment in general, in inch-pounds.

A=Steel area, in square inches.

f_s=Tensile unit stress in steel.

f_c=Compressive unit-stress in concrete.

b=Breadth of beam (in a T-beam, breadth of flange), in inches.

b'=Breadth of web or stem in a T-beam, in inches.
d=Depth of beam from compressive surface to center of steel, in inches.
t=Thickness of flange, in inches.
jd=Distance between center of compression and center of steel, in inches.
k=Ratio of depth of neutral-axis to effective depth, d.
V=Total shear, in pounds.
v=Shearing unit-stress, in pounds per square inch.
u=Bond stress per unit-area of bar.
o=Circumference or perimeter of bar, in inches.
Σo=Sum of the perimeters of all bars, in inches.
s=Distance apart of the stirrups.

69. **Rectangular Beams.** In a rectangular beam, neither the allowable working compressive stress in the concrete nor the allowable tension in the steel should be exceeded. These stresses in practice may be determined by the following formulas:

$$f_s = \frac{M}{.87\,Ad} \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$f_c = \frac{2M}{jkbd^2} \quad \ldots\ldots\ldots\ldots \quad (2)$$

For 0.8 per cent steel, which gives the stresses already suggested for 2,000-pound concrete, $j = 0.88$, and $k = 0.38$, so that the value of f_c becomes approximately

$$\frac{6M}{bd^2}$$

70. For a design based on working stresses recommended in paragraphs 60, 66, and 67 (that is, compression in concrete, 650 pounds per square inch; tension in steel, 16,000 pounds per square inch; and ratio of elasticity of 15), the depth of the beam is

$$d = \frac{1}{10}\sqrt{\frac{M}{b}} \quad \ldots\ldots\ldots\ldots \quad (3)$$

In order to have the specified tension and compression so that the above formula will apply, the percentage of steel must be 0.8 per cent. The area of cross-section of tensile steel reinforcement is therefore:

$$A = 0.008bd \quad \ldots\ldots\ldots\ldots \quad (4)$$

In using these formulas, the maximum bending moment, **M**, is computed in inch-pounds, the breadth **b** is assumed, and the depth to steel, **d**, is found from the formula. The full depth is obtained by adding to **d** a thickness of concrete required to imbed and protect the steel. The area of steel is then obtained from formula (4). Shear and bond are considered in succeeding paragraphs.

71. **T-Beams.** Where adequate bond between slab and web of beam is provided, the slab may be considered as an integral part of the beam, and its effective width may be determined by the following rules:

(a) It shall not exceed one-fourth of the span length of the beam;

(b) Its overhanging width on either side of the web shall not exceed four times the thickness of the slab.

72. Following the above requirements, and where ample provision has been made for shear, the formulas just given for rectangular beams may be applied without material error so long as the depth **d** is not greater than 5 times the thickness of the slab.

73. In using the rectangular beam formulas, the width of the slab as above specified is taken as the breadth of beam, **b**, in computing compression; but in the formulas for shear and bond, the width of the stem or web is used.

74. The area of steel may be obtained (when the depth of beam, **d**, does not exceed 5 times the thickness of the slab), by the formula:

$$A = \frac{M}{.87 f_s d} \quad \ldots\ldots\ldots\ldots \quad (5)$$

For 16,000-pound stress in steel, this formula becomes:

$$A = \frac{M}{14{,}000\,d} \quad \ldots\ldots\ldots\ldots \quad (6)$$

75. The width of the stem or web of the T is governed by the proper embedding of the rods and the area required to resist diagonal tension, as indicated below. Web reinforcement is considered in paragraphs 86 to 95.

76. **Floor-Slabs.** Floor-slabs should be designed and reinforced as continuous over the supports. If the length of the slab exceeds 1.5 times its width, the entire load should be carried by transverse reinforcement. Square slabs may well be reinforced in both directions, using one-half the computed reinforcement in each direction.

77. The loads carried to beams by slabs which are reinforced in two directions will not be uniformly distributed to the supporting beam, but may be assumed to vary in accordance with the ordinates of a triangle. The moments in the beams should be calculated accordingly.

78. **Continuous Beams and Slabs.** In computing the positive and negative moments in beams and slabs continuous over several supports, due to uniformly distributed loads, the following rules are recommended:

(a) That for floor-slabs the bending moments at center and at support be taken at $\frac{wl^2}{12}$ for both dead and live loads, where w represents the load per linear foot and l the span length.*

(b) That for beams the bending moment at center and at support for interior spans be taken at $\frac{wl^2}{12}$, and for end spans it be taken at $\frac{wl^2}{10}$ for center and adjoining support, for both dead and live loads.*

* A still more conservative plan is to use $\frac{wl^2}{10}$ at the middle of all spans

79. In the case of beams and slabs continuous for two spans only, or of spans of unusual length, more exact calculations should be made. Special consideration is also required in the case of concentrated loads.

80. **Bonding Strength and Spacing of Bars.** In direct pull or direct compression a bar must be embedded a length sufficient to give a working strength in bond equivalent to the working strength of the steel in tension or compression. For 2,000-pounds concrete, in which 80 pounds per square inch is permitted in bond, and a working strength of 16,000 pounds per square inch in the steel, plain round bars thus require an embedded length of fifty diameters.

81. The bond stress in the horizontal bars in a beam may be represented by the formula:

$$u = \frac{V}{jd\Sigma o} \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

82. With the unit-bond of 80 pounds per square inch (assuming $jd = \frac{7}{8}\, d$), the total circumference of tension rods at any section of the beam should be at least:

$$\Sigma o = \frac{V}{70d} \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

83. For T-beams, b' is substituted for b, and jd may be taken as approximately the distance from center of slab to steel.

84. Where high bond resistance is required, the deformed bar is a suitable means of supplying the necessary strength. Adequate bond strength throughout the length of a bar is preferable to end anchorage; but such anchorage may properly be used in special cases. Anchorage furnished by short bends at a right angle is less effective than hooks consisting of turns through 180 degrees.

85. The lateral spacing of bars should not be less than two and one-half diameters, center to center, nor should the distance from the side of the beam to the center of the nearest bar be less than two diameters.

The clear spacing between two layers of bars should be not less than ½ inch.

86. **Shear and Diagonal Tension.** Calculations for web resistance shall be made on the basis of maximum shearing stress as determined by the formulas hereinafter given. When the maximum shearing stresses exceed the value allowed for the concrete alone, web reinforcement must be provided to carry the diagonal tensile stresses involved. This web reinforcement may consist of bent bars, or inclined or vertical members attached to or looped about the horizontal reinforcement. When inclined members are used, the connection to the horizontal reinforcement shall be such as to insure against slip.

87. Experiments bearing on the design of details of web reinforcement are not yet complete enough to allow more than general and tentative recommendations to be made. It is well established, however, that a very moderate amount of reinforcement, such as is furnished by a few bars bent up at small inclination, increases the strength of a beam against failure by diagonal tension to a considerable degree; and that a sufficient amount of web reinforcement can readily be provided to increase the shearing resistance to a value three or more times that found when the bars are all horizontal and no web reinforcement is used.

88. The Joint Committee recommend the following allowable values for maximum shearing stresses for concrete whose crushing strength is 2,000 pounds at 28 days:

(a) For rectangular beams with horizontal bars only, web reinforcement is necessary when $\frac{V}{bjd}$ is greater than 40, or (assuming distance between centers of tension and compression to be $\frac{7}{8}d$) when $\frac{V}{bd}$ is greater than 35.

(b) For rectangular beams in which a part of the horizontal reinforcement is used in the form of bent-up

bars arranged with due respect to shearing stresses, a higher value may be allowed, but not to exceed 60 pounds per square inch. In this case (assuming $jd=\frac{7}{8}d$), stirrups will be required when $\frac{V}{bd}$ is greater than 52.

(c) In any case, no matter how thoroughly reinforced for diagonal tension, the total shear should not exceed 120 pounds per square inch, that is (assuming $jd=\frac{7}{8}d$), bd must never be less than $\frac{V}{105}$.

89. For T-beams the same rules apply, except that only the web of the beam is effective; hence b' must be substituted for b.

90. In the calculation of web reinforcement to provide a strength of 120 pounds per square inch, the concrete may be counted upon as carrying one-third of the shear, or, for 2,000-pound concrete, 40 pounds per square inch. The remainder may be provided for by means of metal reinforcement consisting of bent bars or stirrups, but preferably both. The area of a stirrup, acting in tension, must be proportioned to the force equal to the whole horizontal shear produced between the two adjacent stirrups, less the amount to be carried by the concrete. This total horizontal shear may be found by multiplying the distance between stirrups by the average horizontal unit-shear, which is equal to the vertical unit-shear, and is represented by the expression $\frac{V}{jd}$.

91. In accordance with this method the stress in a vertical stirrup will be equal to $\frac{Vs}{jd}$; and in a stirrup or bent rod at 45 degrees, it will equal $\frac{0.7Vs}{jd}$ in which s = horizontal spacing—that is, the distance apart, of stirrups or bent rods.

92. In these formulas, V is taken as the proportion of total shear assumed as carried by the reinforcement,

93. The longitudinal spacing of stirrups shall not exceed three-fourths the depth of the beam in the portion of the beam where the shearing stresses exceed the allowable shearing value of the concrete.

94. It is important that adequate bond strength be provided to fully develop the assumed strength of all shear reinforcement.

95. Inasmuch as small deformation in the horizontal reinforcement tends to prevent the formation of diagonal cracks, a beam will be strengthened against diagonal tension failure by so arranging the horizontal reinforcement that the unit-stresses at points of large shear shall be relatively low.

96. **Columns.** It is recommended that the ratio of unsupported length of column to its least width be limited to fifteen.

97. The effective area of the column shall be taken as the area within the protective covering, as defined in paragraph 3. Or, in the case of hooped columns or columns reinforced with structural shapes, it shall be taken as the area within the hooping or structural shapes.

98. Columns may be reinforced by means of longitudinal bars; by bands or hoops; by bands or hoops together with longitudinal bars; or by means of structural forms which in themselves are sufficiently rigid to act as columns. The general effect of bands or hoops is greatly to increase the "toughness" of the column and its ultimate strength; but hooping has little effect upon its behavior within the limit of elasticity. It thus renders the concrete a safer and more reliable material, and should permit the use of a somewhat higher working stress. The beneficial effects of "toughening" are inadequately provided by a moderate amount of hooping, a larger amount serving mainly to increase the ultimate strength and the possible deformation before ultimate failure.

99. The following recommendations are made for

the relative working stresses in the concrete for the several types of columns:

(a) Columns with longitudinal reinforcement only, the unit-stress recommended in paragraph 58.

(b) Columns with reinforcement of bands or hoops, as specified below, stresses 20 per cent higher than given for a.

(c) Columns reinforced with not less than 1 per cent and not more than 4 per cent of longitudinal bars, and with bands or hoops, stresses 45 per cent higher than given for a.

(d) Columns reinforced with structural steel column units which thoroughly encase the concrete core, stresses 45 per cent higher than given for a.

100. In all cases, in addition to the stress borne by the concrete given above, longitudinal reinforcement is assumed to carry its proportion of stress in accordance with the ratio of its elasticity to concrete. For example, with a working stress in concrete of 450 pounds per square inch, the longitudinal reinforcement may be assumed to carry $15 \times 450 = 6{,}750$ pounds per square inch.

101. The hoops or bands are not to be counted upon directly as adding to the strength of the column.

102. Bars composing longitudinal reinforcement shall be straight, and shall have sufficient lateral support to be securely held in place until the concrete is set.

103. Where bands or hoops are used, the total amount of such reinforcement shall be not less than 1 per cent of the volume of the column enclosed. The clear spacing of such bands or hoops shall be not greater than one-fourth the diameter of the enclosed column. Adequate means must be provided to hold bands or hoops in place so as to form a column the core of which shall be straight and well-centered.

104. Bending stresses due to eccentric loads must be provided for by increasing the section until the maximum stress does not exceed the values above specified.

105. **Splicing of Bars.** Wherever in tension reinforcement it is necessary to splice the reinforcing bars, the length of lap shall be determined on the basis of the safe bond stress and the stress in the bar at the point of splice; or a connection shall be made between the bars of sufficient strength to carry the stress. Splices at points of maximum stress should be avoided. In columns, large bars should be properly butted and spliced; small bars may be treated as indicated for tension reinforcement, or their stress may be taken off by being embedded in large masses of concrete. At foundations, bearing plates should be provided for large bars or structural forms.

106. **Reinforcing for Shrinkage and Temperature Stresses.** Where large areas of concrete are exposed to atmospheric conditions, the changes of form due to shrinkage (resulting from hardening) and to action of temperature, are such that large cracks will occur in the mass, unless precautions are taken so to distribute the stresses as either to prevent the cracks altogether or to render them very small. The size of the cracks will be directly proportional to the diameter of the reinforcing bars, and inversely proportional to the percentage of reinforcement and also to its bond resistance per unit of surface area. To be most effective, therefore, reinforcement should be placed near the exposed surface and well distributed, and a form in reinforcement used which will develop a high bond resistance.

Concrete Bridges

Classification of Bridges in General. A bridge is a structure which furnishes a passage-way from one side of an opening or depression to the other side. A bridge may be needed to cross a valley, gulch, stream, canal, road, or railway track. If the bridge is supported at the two ends only, it is said to be a bridge of one **span,** and the end supports are called **abutments;** if the bridge has one or more intermediate supports, it is a bridge of two or more spans, and the intermediate supports are known as **piers.** The abutments and piers compose the **substructure;** and the remainder of the bridge, the **superstructure.** The superstructure may be of any one of several forms, and bridges are classified accordingly, as **beam bridges, arch bridges,** and **suspension bridges.** The difference in the types is in the manner in which the structures carry the loads that come upon them, and, consequently, in their external form.

Beam bridges are described in the word **beam,** which signifies a member under a bending stress, having compression in the top, and tension in the bottom. Beam bridges are the most generally used, and are particularly adapted for short spans, although the modern steel truss bridge is a beam bridge.

A log laid across a creek was probably the

first bridge of any kind, and embodies the essentials of the beam bridge of to-day.

Arch bridges carry the load in direct compression throughout the arch ring, and transmit the pressure downward and outward against the abutment. The ancient Romans utilized the arch extensively when they found that the principal building material they had on hand—stone—was not adapted either in its properties or in its form for the construction of beams of any length.

Fig. 35. Aqueduct of Pont du Gard, near Nismes, in Southern France.

Built by ancient Romans.

Fig. 35 is an illustration of the Pont du Gard, an arch structure built by the Romans in Southern France in the first century after Christ, showing the wonderful engineering skill of the ancients.

Suspension bridges are designed to support the loads that come upon them, by means of ropes or cables which are either fastened to the banks above the ends of the bridge, or laid over towers and anchored in the ground. This type of bridge has made it possible to span tremen-

dous distances, but is not very desirable for ordinary lengths.

Bridges are essential to communication and commerce between nations and communities, and have been developed with the advance of civilization. The greatest strides in bridge construction were taken in the days when the steam railroad came into being. A footpath or a wagon road can follow the contour of the ground to a certain extent, but the tracks of a railroad must be reasonably straight and reasonably level; and the streams and valleys which are intersected must be crossed on structures strong enough to carry the repeated heavy loads. The interurban trolley has followed the steam railroad, and the accompanying improvement of rural districts has created new demands for adequate bridges. Engineers are ever on the lookout for economical materials and methods for bridge construction, and their latest find has been reinforced concrete, which has already replaced stone and wood and has opened up new fields for the bridge-builder.

Advantages of Concrete and Reinforced Concrete for Bridge Construction. In order to appreciate the advantages of concrete as a material for bridges, it is necessary to understand the requirements for a good bridge and for an economical bridge. These requirements depend to a large extent on the purpose of the structure; and in the articles which follow, concerning the various classes of bridge structures, the ad-

vantages of concrete in connection with the requirements of each particular class will be brought out in detail.

It may be said in general, however, that a "good" bridge must have sufficient strength and stability to carry its loading, and must be designed to fulfil the conditions imposed by its location. An economical bridge is a "good" bridge of the lowest first cost, combined with durability and permanence sufficient to keep the expense of maintenance and renewal as low as possible. From these statements it follows that a bridge may serve its purpose excellently, and still not be economical; also, that a bridge may have a low first cost, and not be economical.

Taking the qualities of strength and stability first, it is easy to show the advantages of reinforced concrete construction. Reinforced concrete is now well understood, and designs may be made upon a rational basis, the steel carrying the tensile stresses, and the concrete the compressive stresses. The steel is well protected and can never deteriorate, while the concrete gains in strength as the years go by. The mass and weight of the concrete work make it proof against vibration and the danger of floods and winds.

The first cost of reinforced concrete bridges is slightly greater than that of wooden bridges, about the same as that of steel bridges for short spans, and considerably less than that of stone bridges. The analysis of comparative costs is

BRIDGE OVER SANGAMON RIVER AT DECATUR, ILLINOIS.

On line of Wabash Railroad. The bridge is double-track; its four skew arches rest on piers 100 feet center to center along axis of bridge.

thoroughly treated in the article on "Comparative Cost of Concrete Bridges."

The cost of maintenance is a large item for wooden and steel bridges, and both kinds must be renewed within 10 to 25 years; the maintenance cost for a concrete bridge is nothing, and the bridge should last forever.

A bridge company which makes a specialty of reinforced concrete highway bridges advertises the following advantages for this type of construction:

A properly constructed concrete bridge is absolutely indestructible.

A concrete bridge is the only bridge that grows stronger with age.

As time passes, traffic on our highways grows heavier; steel and wooden bridges grow weaker; concrete bridges grow stronger. To build a concrete bridge, then, is just plain common sense.

Portland cement is the most perfect coating known for the protection of steel.

A concrete bridge provides a continuous gravel roadway. Wooden floors for bridges are an expensive nuisance. Concrete bridges require no floor renewals.

Concrete bridges are rust-proof, frost-proof, flood-proof, and fireproof.

Concrete bridges require neither painting nor repairs.

Concrete bridges are permanent improvements.

A concrete bridge can be widened at any time without re-building.

To make a bridge flood-proof, pave the bed of the stream to prevent scour, and then build the bridge in a solid monolithic mass so that it will stay.

A concrete bridge once built, is built for all time.

Concrete bridges are built with labor hired from the immediate vicinity of the bridge; with gravel or stone purchased in the immediate locality; and with cement secured from local agents. The greater part of the expense for such a bridge is thus returned to the county.

The money that taxpayers expend for a concrete bridge is returned to the taxpayers for labor and material.

The beauty of horseshoe concrete arches lies in their common sense.

Concrete bridges are the handsomest for park bridges, the most durable for highway bridges, the most serviceable for railway bridges.

Bridges built of concrete will endure as monuments for all time.

CONCRETE ARCH BRIDGES

An arch-ring carries the loads which come upon it, by means of its strength in compression, and the resistance of the abutments upon which it exerts its thrust. For this reason, any material with sufficient compressive strength may be used to construct an arch. Stone masonry has served the purpose for centuries, but concrete has come to take its place. When reinforced with embedded steel, concrete arches can be built of daring spans, with thin rings and low crowns; the steel gives the arch a certain amount of flexibility which enables it to adjust itself to moving loads, settlement, temperature changes, and other conditions that might rupture an unreinforced arch.

The theory of the internal stresses in an arch-ring and the design of arch bridges are

extremely difficult and involved; the highest engineering skill has been required to master the subject, and mathematicians have never ceased to wrestle with it. This, however, is not as serious as it might seem; many of the difficulties are due to the fact that the problem is really indeterminate and many refined methods are unnecessary. Arch-rings have a way of adjusting themselves to take their burden as direct compression; and, if the proper precautions are taken to make the abutments absolutely unyielding, the arch-ring may be designed, as far as its thickness and general outline are concerned, by empirical rules based on the experience gained from past achievements. The details of the design and reinforcement of concrete arch-rings are to be found in a number of standard works; but a study of actual structures which have recently been built will give the most practical results.

The arch-ring is only a part, important as it is, of the complete arch bridge; and the main difference in the various types of arch bridges is in the design of the superstructure.

Before proceeding to the description of examples of the various classes and types, it would be well to define the technical terms relating to arch bridges and their details.

Definitions of Terms

Arch-Barrel—The name given to the arch proper, when referred to as having length in a direction parallel to its axis.

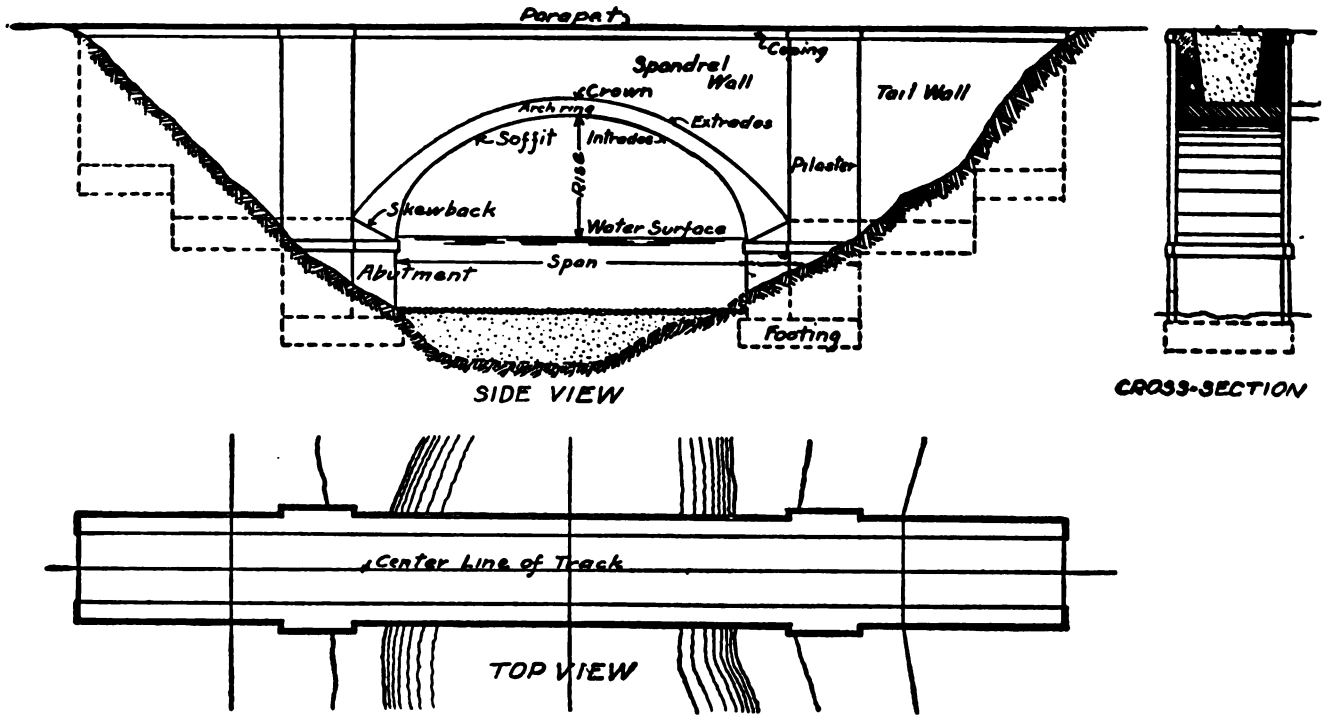


Fig. 36. Typical Concrete Arch Bridge.

Arch-Ring—The outline of a vertical cross-section of the arch-barrel perpendicular to the axis.

Soffit—The under surface of the arch-barrel.

Intrados—The lower or inner curve of the arch-ring.

Extrados—The upper or outer curve of the arch-ring.

Springing or Springing Line—The intersection of the soffit with the face of the abutment; the point or line where the curvature of the intrados or soffit begins.

Crown—The highest point of the arch-ring.

Skewbacks—The inclined bearing on the abutments, upon which the arch-ring rests.

Haunches—That part of the extrados directly above the skewbacks.

Span—The horizontal distance between springings.

Rise—The vertical distance from the level of the springing to the intrados at the crown.

Spandrels—A general term designating the space between the arch-ring and the top of the bridge.

Spandrel Walls—The walls resting on the arch-barrel and supporting the bridge floor or parapet.

Parapets—The walls or tops of walls forming the sides of the bridge floors; also low spandrel walls.

Tail Walls—The continuation of the spandrel walls behind the arch abutments.

Fig. 36 is a view of a common type of arch bridge, and shows the parts defined above.

The first application of concrete to bridge work was probably in the construction of arches, which are essentially masonry structures. The first arches in the United States seem to be the two 25-ft. spans carrying Pine Road across Pennypack Creek in Philadelphia, Pa. This bridge was designed and built by Mr. C. A. Frik, superintendent of bridges for the city in

1893. Although this is a non-reinforced structure, 1½-in. wire mesh nets were placed about 2 ft. apart, horizontally and vertically, apparently with no fixed idea of their function in caring for stresses, but merely in an effort to strengthen the work.

It is interesting to note that in 1885 a design for a reinforced concrete bridge was submitted to the Bridge Commissioners of New York City for the Washington Bridge over the Harlem, by the late Thomas C. Clarke. This bridge was to consist of three 285-ft. arches built of concrete, with a rock face, and reinforced slightly at the haunches and crown with iron beams. Although the design was at first accepted by the Commissioners, it was afterward rejected on account of its extreme novelty.

One of the earliest, if not the earliest, specimens of the concrete arch bridge on this side the Atlantic, is on the Ewarton branch of the Jamaica Railway, Jamaica, W. I. This bridge, which is one of three viaducts, all somewhat similar, consists of four full-centered 50-ft. plain concrete arches. It was built in 1881. It is of remarkably good design, even measuring by present-day standards.

The short lapse of time from the 25-ft. span across Pennypack Creek to its 232-ft. span neighbor across the Wissahickon, at Walnut Lane, is indicative of the rapidity with which the art of concrete bridge building has advanced.

Highway Arch Bridges. Highway arch

bridges are usually low and flat, and vary in span length from 20 to 100 feet. The ordinary type consists of an arch-barrel and spandrel walls, with an earth filling between the walls. Ornamental concrete parapets are often used, although ordinary gaspipe railing is very common. The width of these bridges ranges from 14 feet for small creek crossings, to 60 feet or over for structures carrying city streets.

Plate 3 (**A**) illustrates a typical highway arch of 95-foot span.

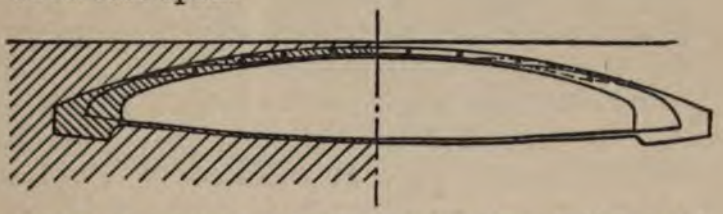


Fig. 37. Cross-Section of Yorktown Bridge Shown in Plate 3 (A).

Fig. 37 gives a cross-section of the same arch. This bridge was built in 1904, at Yorktown, Indiana. It has a span of 95 ft.; a rise of 11 ft. 1 in.; a height of opening of 15 ft. 7 in., and crown thickness of 26 inches. The roadway is 16 ft. wide. The arch-rods are ¾ in. square, spaced 6 inches. The parapets are monolithic concrete, 18 in. by 3 ft. high. The design was made for a 20-ton roller, or 200 pounds per sq. ft.

Another typical arch highway bridge is shown in Plate 3 (**B**). The rise of the arch is 7 ft. 6 in., and the width 19 ft. 6 in., from outside to outside wall. The arch-ring is only 12 in. thick

at the crown, and 21 in. at the haunches. A moving load of 100 pounds per square foot, plus an 8-ton traction engine, is provided for.

For ordinary highway construction where long spans are required, and where heavy loads such as traction engines and their accompanying machines or where heavy earth-fills will occur, an arch of this type is especially suitable. The construction has all the strength of the masonry arch, with much greater elasticity. In case of settlement of the abutments, the reinforcing steel will take strains that would cause large cracks in ordinary masonry.

In cities and towns where it is necessary to have the streets cross a stream, the reinforced concrete arch not only insures strength and stability, but is capable of such varied artistic treatment that it is being almost universally adopted in municipal work.

The Walnut Lane arch in Fairmount Park, Philadelphia, Pa., is the largest concrete arch in the United States at the present day. It carries a boulevard which will connect the suburbs of Germantown and Roxborough. The contract price was $253,551. See Fig. 38.

The bridge is 585 ft. over all and consists of a main arch of 232 ft. between abutments, approached on one side by two and on the other by three arches of 53-ft. span. The roadway is 40 ft. wide with two 10-ft. sidewalks. The whole structure is built throughout of concrete, and, except in some walls and columns hereafter

mentioned, is not reinforced. It is designed to carry highway traffic.

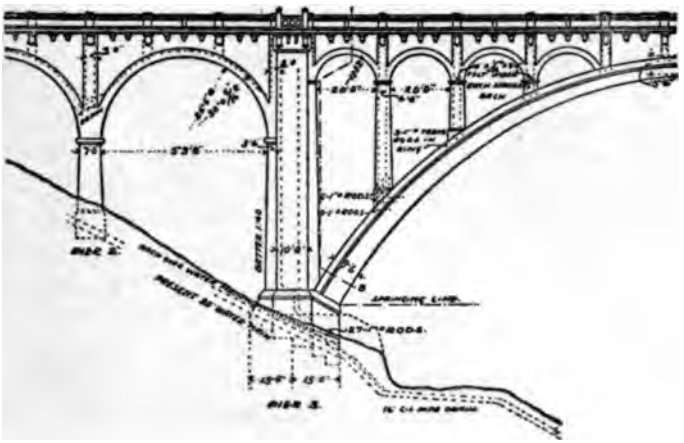
The **main arch,** which is a three-centered curve 232 ft. span, at springing line, 70 ft. 3 in. rise, is made up of twin arch-rings each 21 ft. 6 in. wide and 9 ft. 6 in. thick at the haunch, and 18 ft. wide and 5 ft. 6 in. thick at the crown. These twin arches spring from abutments 25 ft. 6 in. wide, founded some 12 ft. below the surface on stepped-footings reaching to solid rock. The main piers or main arch abutments are solid for the width of the bridge or main arch abutments are solid for the width of the bridge to a point immediately above the springing line of the arches, above which point they divide into two parts each of the same width as the arch-rings, and joined together at the top by a small counter-arch.

The **abutments** are reinforced near the bottom by one plane of 1-in. square rods parallel to the springing face of the arch and running transverse to the line of the bridge.

From each arch-ring rise T-shaped cross walls of concrete, which act as supporting piers for the spandrel arches. There are in the line of the bridge two of these pillars and accompanying arches to each arch-ring, making four lines of spandrel arches. The pillars nearest the abutments are bonded with the arch-ring by 1-in. square rods. The arch-ring is reinforced under each pillar by three 1-in. square rods running transverse to the line of the arch.

The **floor system** is carried on I-beams, 15-in. 42-lb. beams on the outside, and 20-in. 65-lb. beams in the middle, which span across the spandrel walls. These I-beams are tied together by $\frac{7}{8}$-in. tie-rods, and the floor system is carried between them by jack arches. Over the spandrel walls and main piers, the 15-in. I-beams are omitted, and 1-in. square rods are substituted as reinforcement.

The **roadway** is made up of a cinder-fill on top of the embedded I-beams mentioned above, topped off with a



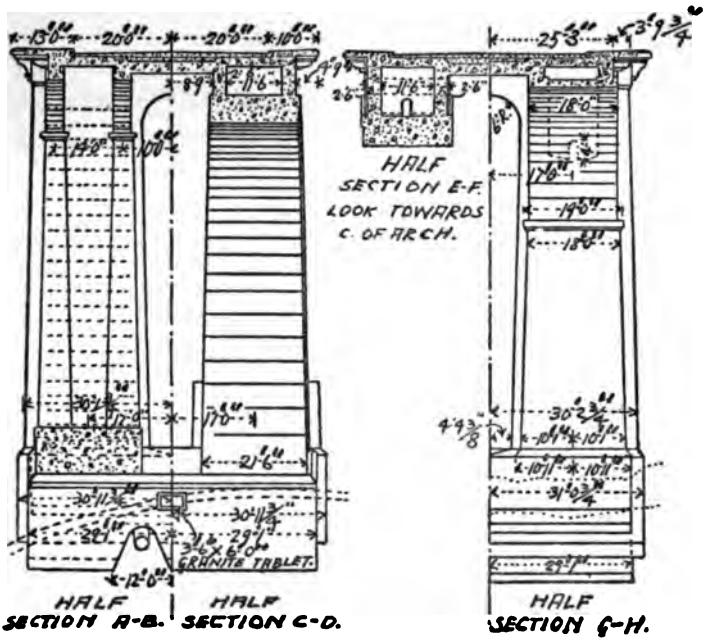
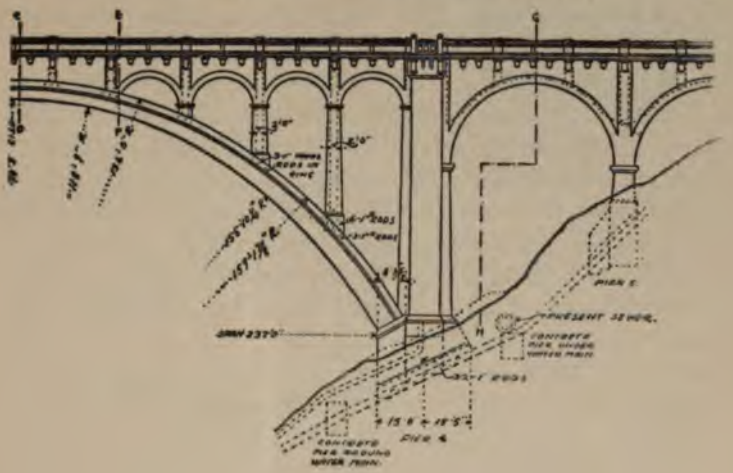
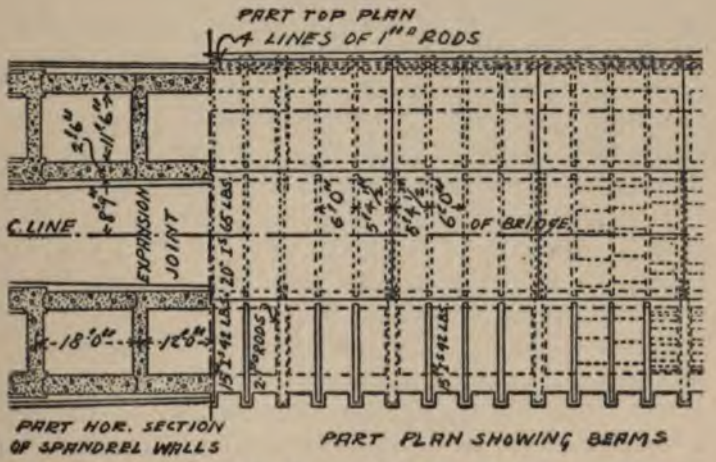


Fig. 38. General Elevation, Part Plan, and Section of the 232-Foot Arch and





Two Typical 53-Foot Arches of the Walnut Lane Bridge, Philadelphia, Pa.

6-in. layer of concrete and a final 3½-in. layer of asphalt. The sidewalk is of concrete reinforced by 1-in. square rods.

The railing is of concrete, with the pedestals and pilasters cast in place, and the balusters moulded separately and set afterward. All copings, moulds, and cornices that project from the main face of the wall are reinforced with small rods bonding back into the wall.

Expansion is provided for by making each floor system between spandrel pillars fixed to one end pillar and movable on the top of the other.

The small approach arches are 53 ft. in span, and 1 ft. 6 in. arch thickness, with an exposed arch face 2 ft. 3 in. deep. All the details of columns and floor beams are the same as in the large arch, except that there are no spandrel arches, the outside face being carried to the floor level by a solid wall.

The material used in the construction might be called a rubble concrete. In all foundations, stones of derrick size were allowed to be embedded, and smaller stones embedded with them, but not closer than 2 in. to any face. The concrete in the abutments to the main arch and used in the rest of the work, except the arch-rings, consists of a 1:3:6 mixture, the crushed stone varying from ¾-in. to 1½ in. in size. This is supplemented by the use of stone varying in size from 12 in. largest diameter, to some stones of derrick size. These stones, rough and sharp from the quarry, were deposited in each layer of the concrete when it was in a plastic state, and rammed down to about their mid-depth, thus leaving a bonding line of stones sticking up from each finished layer. The main requirement of the engineer was that these bonding stones should be deposited in a soft concrete so as to have opportunity to get the full benefit of the setting process. In the abutments to the main arch, the embedded stones are of flat shape, an effort being made to place them in

a plane normal to the direction of the resultant thrust of the arch.

When this large-stone process was extended to the arch-rings, a 1:2:5 mixture was used, the embedded stone being not less than one-man size and of such shape that their thickness was approximately one-quarter of the average dimension. They are laid radially in a way resembling the voussoirs of a masonry arch. At the points covered by the spandrel piers and walls, a number of these stones project above the arch-ring to act as dowels.

Railroad Arch Bridges. Plate 4 is an illustration of a 4-span skew railway arch bridge over the Sangamon river near Decatur, Ill. The arches have a clear span of 58 ft. 3½ in., measured on the square, while the piers are 100 ft. center to center, measured along the center line of the bridge. The rise of the arches is 30 ft. At each end are long, hollow abutments. Fig. 39 shows a plan and elevation of the bridge.

The concrete is made of gravel, and its composition is as follows: For arches, slabs carrying tracks, and footings for piers, 1:2½:5. For piers, spandrels, abutments, and lower slabs, 1:3:6. The assumed live load on the structure was 9,000 lbs. per linear foot for each track. The allowed working stresses were 600 lbs. per sq. in. for compression in the concrete, and 12,000 lbs. per sq. in. for tension in the steel.

Plate 5 is an illustration of a double-track railway bridge of one 100-ft. and two 80-ft. arch spans.

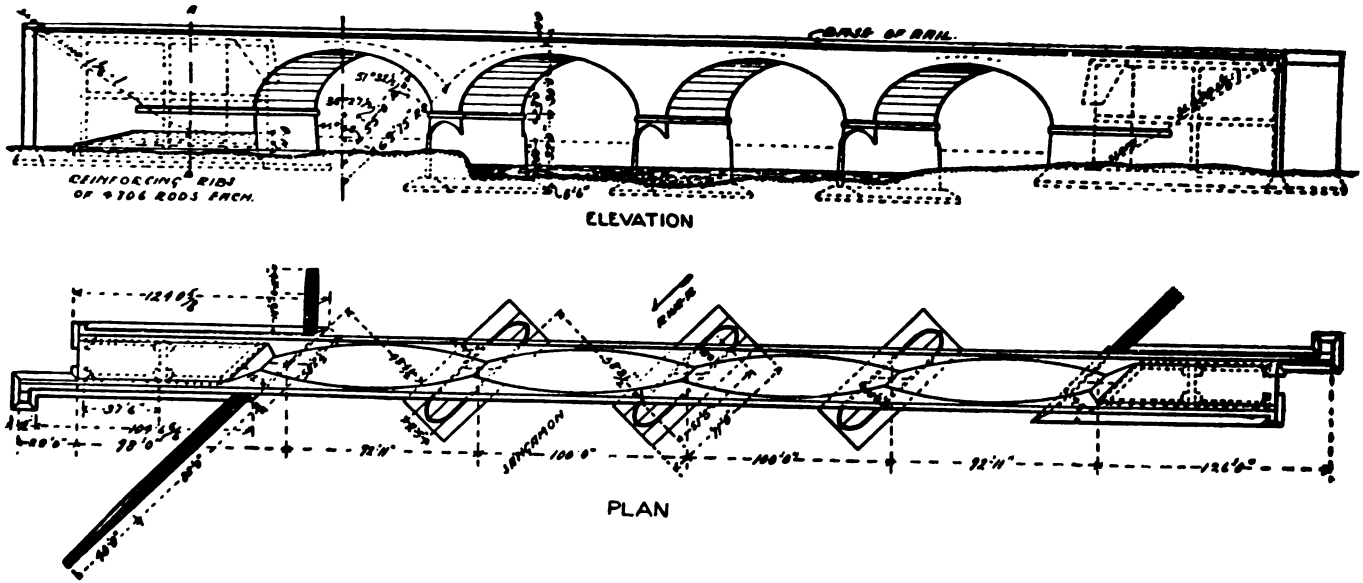


Fig. 39. Reinforced Concrete Skew Arch Bridge over Sangamon River.
On line of Wabash Railroad. See Plate 4.

GIRDER AND SLAB BRIDGES

Girder and slab bridges are known as **beam bridges**; and carry the loads which come upon

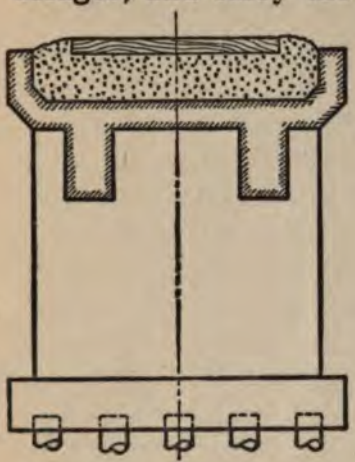


Fig. 40. Cross-Section of a Railroad Girder Bridge.

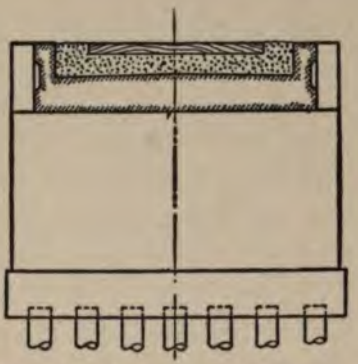


Fig. 42. Cross-Section of a Railroad Slab Bridge.

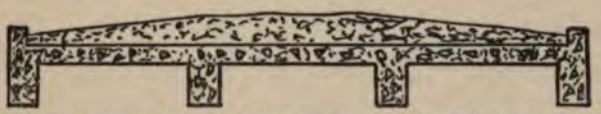


Fig. 41. Cross-Section of a Concrete Girder Highway Bridge.

Fig. 43. Cross-Section of a Concrete Slab Highway Bridge.

them by their resistance to bending. They are extensively used for short spans and low, shallow crossings. These bridges are very interesting as examples of the advantages of reinforced concrete construction, because it is only the use of the steel reinforcement which makes it pos-

sible for them to resist the bending stresses which the applied loads and their own weight bring upon them. The reinforcement is only an assistance and improvement in the case of an arch bridge; in the case of a beam bridge, it is the essential feature.

The difference between a **girder** bridge and a **slab** bridge of reinforced concrete, is shown by Figs. 40, 41, 42, and 43. Figs. 40 and 41 are cross-sections of girder bridges, the former a railway, the latter a highway structure. Figs. 42 and 43 are cross-sections of slab bridges, the former for a railway, and the latter for a highway. The slabs are seen to be of uniform depth, and have the advantage of taking up less room than the girder bridges, which are made up of deep, narrow beams supporting a thin reinforced concrete floor.

The **flat slab bridge** is the simplest to design and construct, and also proves to be the most economical in materials when used for spans up to about 20 feet. For spans from 20 to 35 feet or thereabouts, the girder type is the best to use. Beams longer than 35 feet are rarely built; an arch is generally used for such spans.

The design of reinforced concrete slab and girder bridges is based on the same principles as the design of reinforced concrete slabs and girders in general, when the loading is known. The loading for railway bridges ordinarily considered may be found below under the heading "Reinforced Concrete Design for Bridge Work."

BRIDGE OVER VERMILION RIVER NEAR DANVILLE, ILLINOIS.

On line of Big Four Railway. The bridge is double-track, with one 100-foot and two 80-foot arches.

A large manufacturer of reinforcing materials much used in bridge construction gives the following three classes of loadings for highway bridges:

Class No. 1—Light highway specification answering the purposes of ordinary county traffic where the heaviest load may be taken as a twelve-ton road-roller. Uniformly distributed load, 100 pounds per square foot.

Class No. 2—Heavy highway specification, designed for localities where heavy road-rollers, up to twenty tons, and electric cars of a maximum weight of forty tons, must be provided for. Uniformly distributed load, 125 pounds per square foot.

Class No. 3—City highway specification, designed for heavy concentrated loads and large interurban cars. This classification should be adopted for all city work; the weight of the maximum car has been taken as sixty tons. Uniformly distributed load, 150 pounds per square foot.

Highway Girder and Slab Bridges. Highway bridges are of the greatest practical utility and importance, and the number required in the present state of civilization is extremely large. Good bridges are as necessary as good roads for the advancement of a district, and reinforced concrete is an ideal material for a "good bridge." A concrete bridge is reasonably cheap in first cost, requires the minimum of maintenance, and will last indefinitely. For a structure to be maintained by a public body, as highway bridges usually are, the fewer repairs that are required tbe better.

Portland cement should always be used for

concrete highway bridge construction, because it is stronger and more reliable and hardens more quickly than natural cement.

The cement should be of a standard brand, and not liable to expansion or disintegration, fine, and of uniform quality. It should be free from lumps and stored in a dry place.

For the aggregates in concrete, the sand should be clean and coarse, or a mixture of coarse and fine, the coarse predominating. It should be free from clay, loam, and sticks, organic matter, and other impurities.

Screenings or crusher dust from broken stone may be substituted for sand by altering the proportions so as to give a dense mixture and the same relative volume of aggregates.

Gravel when used should be composed of clean pebbles free from any foreign matter, and containing no clay nor any materials adhering to the pebbles.

It should be screened to remove the sand, and should be mixed afterwards in the proper proportions. However, if by tests, the gravel runs in the proportions of two and one-half to three parts sand, to four or five parts of pebbles, it can be used without screening.

Broken stone should consist of pieces of hard, durable rock, such as limestone or conglomerate.

The water should be clean and free from acids or strong alkalies.

Steel for reinforcement should be of high ten-

sile strength, and of such shape as to form a firm mechanical bond with the concrete.

In mixing concrete for highway bridges or culverts, proportions should be used to give the densest concrete with the maximum strength of the concrete.

The mortar mixture of sand and cement is generally two parts of sand to one part of cement; yet mixtures of two and one-half to three parts of sand to one of cement will give a mortar that is dense and for practical purposes as good on small bridges and culverts as stronger mixtures.

The stone aggregate should not be more than twice that of sand; and in most cases the proportion of four parts of stone will generally make the most desirable mixture, as it allows sufficient mortar to cover all the stone and leaves no rough spots on the surface.

Mix well and mix wet will cure many faults, so-called, in working with concrete.

Exposed surfaces of concrete may be made sufficiently smooth by spading, so as to force the stones back from the surface and allowing the mortar to crowd to the face; the forms should be sufficiently tight to prevent mortar running out. With these precautions, surfaces can be obtained that require very little patching or plastering to make a neat job.

The forms should be made of lumber sufficiently strong to hold itself in line without an excess of bracing, and not bulge or be thrown out

of line by the workmen filling them. All exposed surfaces should be made with dressed lumber, with all joints neatly fitted. The lumber best adapted for building the forms is 2x6-in. stuff with 4x4-in. for the stays.

The handiest ties are one-half-inch bolts of a length necessary to hold the forms together. Bolting the forms requires few nails, and makes a form that can be taken down easily.

The time necessary to leave the forms in place varies considerably with the weather. But

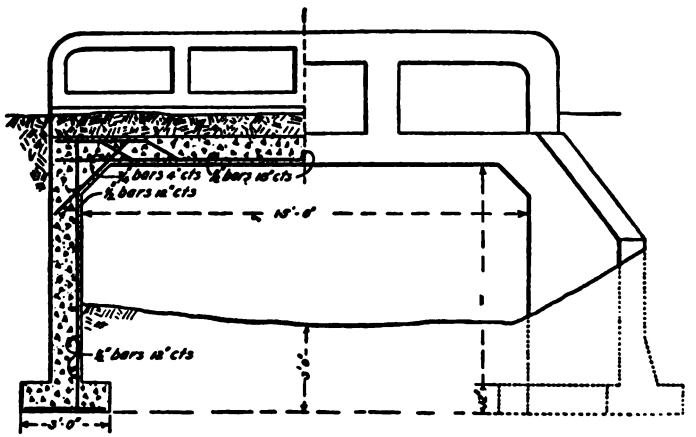


Fig. 44. Standard Bridge of 15-Foot Span, Illinois State Highways.

under ordinary conditions, wing walls and culvert walls can be removed in three days. Slabs of not more than six feet may be removed in five days. Longer spans and arches up to forty feet, require not less than ten days of good drying weather.

In freezing weather, the forms should be left in place as long as possible.

The State Highway Commission of Illinois furnishes advice to township and county highway officials throughout the State in regard to bridges as well as roads; and in many instances, at the request of local authorities, has supplied plans and specifications for the needed structures, and has taken charge of the letting of contracts. According to the annual report of the Commission, reinforced concrete bridges are recommended for spans up to 50 feet.

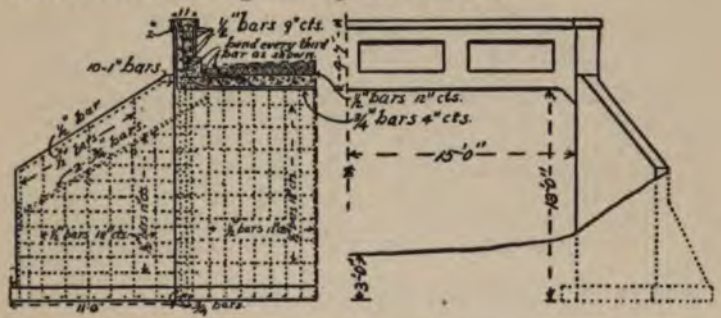


Fig. 45. Standard Bridge of 30-Foot Span, Illinois State Highways.

In Fig. 44 is shown the standard form of bridge adopted by the Commission for spans up to 18 feet. This is a slab bridge, and the main reinforcement is in the direction of the span. The parapets do not carry any of the load.

In Fig. 45 is shown a girder bridge recommended for spans up to 50 feet. In this type the load is carried to the abutments by means of the side girders, which also serve as parapets or railings. The floor slab spans between these girders.

Plate 6 (**A** and **B**) illustrates typical country

highway bridges. The bridge shown in Plate 6 (**A**) spans 35 ft. between abutments. It is 18 ft. wide; and the floor spans between the two out-

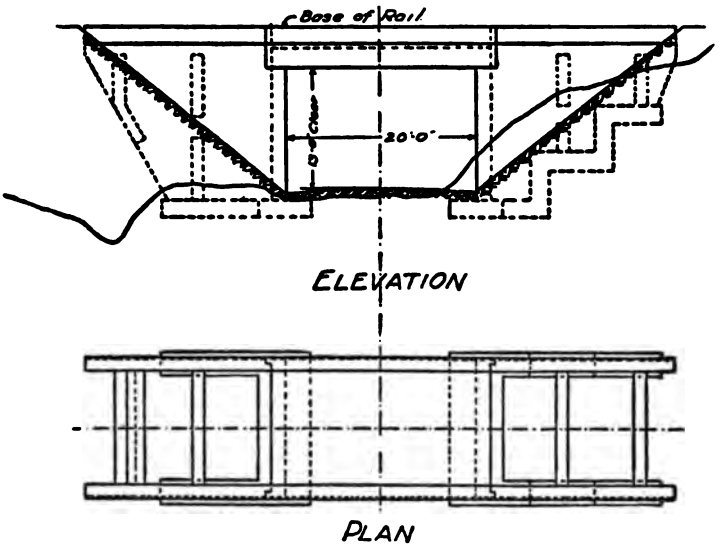


Fig. 46. Typical 20-Foot Slab Railroad Crossing over a Highway.

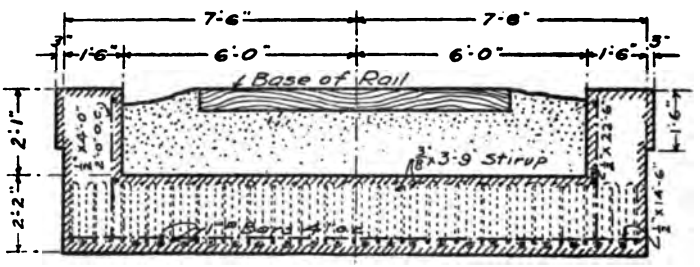


Fig. 47. Cross-Section of Slab Bridge Shown in Fig. 46.

side girders, which carry the load to the abutments.

Railway Girder and Slab Bridges. Reinforced concrete slab and girder construction is

well adapted to short-span railway bridges, and is extensively used for such structures. Short-span bridges in railroad work are required for a number of purposes—as street crossings, highway crossings, small stream crossings, trestles, cattle-passes, and culverts. Street crossings are described under the heading "Track Elevation Bridges;" and trestles and culverts are treated under their respective class names.

Fig. 46 shows a plan and elevation of a typical 20-ft. slab railroad crossing over a highway. Fig. 47 gives a cross-section of the slab.

Plate 6 (**C**) illustrates a cattle-pass which represents the acme of simplicity in structures of this kind. The side walls are solid concrete abutments with a low percentage of reinforcing steel used.

The top of the culvert is a solid concrete slab reinforced with bars. These bars span across from wall to wall. They are placed about 10 inches apart in the slab.

The embankment at this point is high enough to allow ample head-room, and still enough clearance between the top of the slab and the track to permit plenty of ballast.

The first cost of this structure is no greater than if built of heavy timber, and the maintenance cost is nil. The culvert will stand for all time, without need of repairing or replacing any portion. There is nothing to decay or rot out.

Track Elevation Bridges. One of the great engineering problems of the present day is the

problem of eliminating railroad grade crossings in populous districts. In some cases the streets are carried over the tracks on viaducts, but usually the tracks are elevated and carried over the streets on bridges. These track-elevation bridges are usually made up of short spans—one

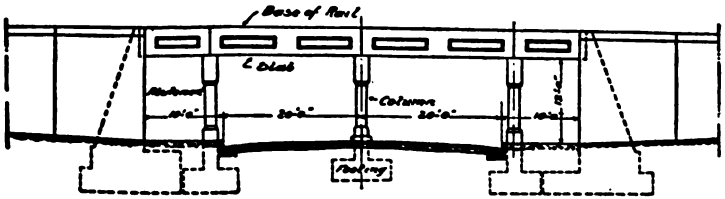


Fig. 48. Elevation of Reinforced Concrete Track Elevation Bridge.

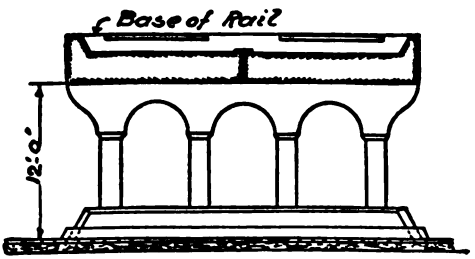


Fig. 49. Cross-Section of Reinforced Concrete Track Elevation Bridge.

span over each sidewalk, and one or two spans over the roadway. It is essential that these structures have solid waterproof floors, in order to protect the traffic in the street from drippings and falling objects from the tracks above. It is only recently that reinforced concrete has been used or even suggested for these structures; but it has so many advantages that it is rapidly coming into common use. Among the advantages are: Cheapness in first cost, low expenditures

for maintenance, permanence and durability, freedom from vibration and accompanying noise, waterproof floor, and attractive appearance.

The design of track-elevation bridges consists in the design of the **abutments**, the **supporting columns** and the **slabs**.

Figs. 48 and 49 show an elevation and cross-section of a typical two-track track-elevation bridge entirely of reinforced concrete construction.

The following description of the work done by the Chicago, Burlington & Quincy Railroad in Chicago will explain the construction of concrete track-elevation bridges:

The standard type of bridge used in the subways of the C., B. & Q. R. R. track-elevation work in Chicago is a **ballasted-floor bridge**, composed of two 24-ft. 3-in. street spans and two 8-ft. 9-in. sidewalk spans, resting upon solid concrete abutments at the street lines; and three lines of columns and cross-girders, two at curb line and one on center line of street. The decks proper are reinforced concrete deck-girder slabs; and the columns and cross-girders are also composed of reinforced concrete, and rest upon concrete cylinders extending down to bedrock.

The conditions to be met in the design of these bridges (see Fig. 50) were as follows:

(1) Under the city ordinances the subways were to be 66 feet wide, composed of a 46-ft. roadway and two 10-ft. sidewalks, allowing the use of three sets of columns and cross-girders, one in the center line of the roadway, and the other two on the curb lines. The spans were finally determined as shown.

(2) The head-room or clearance, which is 12 ft. and 12 ft 6 in. above established grades in subways.

(3) The bridges being at the eastern end of the Western Ave. yard, it was very desirable that they be so designed that tracks and cross-overs could be placed at any point upon the structure. This requirement could be satisfied only with a ballasted-floor type of bridge.

(4) As thin a floor as possible within the limits of

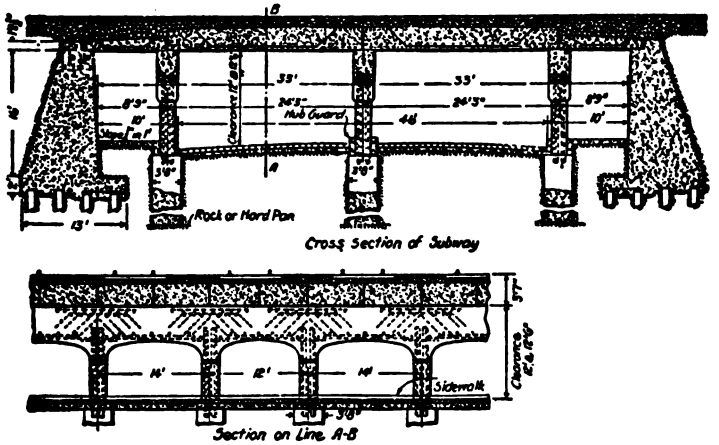


Fig. 50. Typical Bridge with Reinforced Concrete Floor-Slabs and Columns.

Track elevation work, C. B. & Q. R. R., Chicago.

good practice, so as to minimize the depth of fill, approach grades, and height of walls.

(5) A floor that is easily made water-tight.

(6) A floor as near sound-proof as possible.

(7) Comparative cost.

(8) Permanence.

After looking over the field for some time, it was decided that one of the three following would fill about all of the conditions:

(a) A trough-girder bridge composed of a series of

troughs, made of plates and angles, concreted to form a solid deck.

(b) An I-beam span concreted.

(c) A reinforced concrete deck-girder slab.

The different types were drawn up and an estimate made, with the following result, this estimate being per square foot of bridge:

Reinforced deck-girder spans.....100 per cent.
I-beam span .....171 per cent.
Trough girders .....208 per cent.

This shows conclusively that a great saving could be made by the use of the first type.

Abutments. The soil underlying this location is composed chiefly of soft, blue clay and quicksand, and, taken as a whole, is not very desirable material to place a foundation on; but it was decided that with the bearing of the footing, in addition to the piles, it was amply safe to carry the abutment load.

The footings for the several streets were put in during 1905 in advance of the other work, and were built up to a point about three feet above top of footing proper. This was found to be quite a help as a line and lock for the forms.

The abutments are of the solid type, as it was found that a buttressed abutment of this height would cost as much per linear foot, if not more; and as the forms were built and concreted after the temporary bridge was up, the work was done in cramped space.

The forms were continuous, composed of studding and sheeting, the former being 3 inches by 6 inches, and the latter 2-inch tongued-and-grooved. The sides were held together by ¾-in. rods, spaced about 4 ft. C. to C. both vertically and horizontally. This scheme worked far better than wire, which was continually stretching and breaking. With wire it was not wise to fill to a depth of over four feet; while with the rods, the form could be completely filled without danger of collapsing.

The rods are encased in 1½-in. pipe of such lengths that the ends were about 3 inches from the faces of the forms, waste being packed around the rods. This worked very nicely, although there was considerable trouble in pulling the rods. A lever and chain were used to remove rods from wall.

In concreting, the abutments were divided into a number of sections, each containing about a day's work. The mixing was done by machine, driven by power from the hoisting engine, the outfit being all mounted upon a flat car.

The mixer was set directly over the section where possible, and the material delivered by chute; but in cases where the section was too far away to use chutes, a locomotive derrick car having a 1½-cubic yard bucket was used. Facing was obtained by spading, giving a smooth, uniform surface. The mixture was 1:5, composed of 1¼ barrels of cement to a cubic yard of pit-run gravel, this amount of cement being increased where the gravel was very fine. The gravel as a general thing was very fair quality, containing very little clay or other foreign matter, and varied in size from 3-inch ring down to fine sand, the sand being in about the right proportion to fill the voids nicely.

The sections were, as a general thing, completed in one day; but where this could not be done, the surface was thoroughly cleaned the following morning, being scrubbed with wire brushes to remove all laitance, clay, or other foreign substances, and then well rinsed off, before placing the fresh concrete. Frequently heavy horizontal lines are seen upon concrete work, marking the successive days' work. This can, to a great extent, be taken care of by drawing up the forms so as to take up the shrinkage due to the setting of the previous day's work.

Column Footings. The loads upon the columns are as follows: Center column, 204 tons; and sidewalk

column, 138 tons. The question as to kind of foundation lay between the use of an ordinary pile and concrete footing and cylinders, which, after investigation, was estimated to be about a stand-off as regards price. Cylinders were adopted, as they would rest upon a known substance; while the bearing power of a pile footing would be rather indefinite.

These cylinders are 3-ft. 8-in. wells, lagged with 2-in. lumber in about 5-ft. 6-in. lengths, and held from collapse by two 2-in. by ¾-in. steel rings. These rings are made in two pieces, and, after being driven into place, are bolted together. The depth of the cylinders varied from 15 to 65 feet. In all there were about 600 wells dug, averaging about 40 feet deep, and costing approximately $250.00 each.

At most of the crossings, very little trouble was experienced; but at Center avenue, about one-half of the thirty-six holes were very bad. Most of these went down to a point about 60 feet below base of rail almost perfectly dry; but at about this depth, the water would break in in such volume as to drive the digger out until a siphon could be installed. These siphons were the ordinary kind of steam siphon; the only change being made was to put a tee on the intake, and into the tee to put pieces of 2-inch pipe about a foot long. These pipes were capped and drilled full of holes about ⅜ inch in diameter, which prevented large gravel from fouling the siphon. The steam was furnished by two locomotives at a pressure of 140 pounds per square inch, and it took about all the steam a locomotive could furnish to run one siphon.

In concreting, the machine would be got ready with one 1½-yard batch in the mixer, one in the hopper car, and two in the hoppers, all of which could be dropped into the hole within about ten minutes; then the siphon would be hitched onto the derrick line, and started. As soon as the water was down to within about three inches of the bottom, the concrete was dumped in while the der-

rick raised the siphon. The four batches would fill about 10 to 12 feet of the well, which generally stopped the flow. The hole was then filled by chuting the concrete to it.

In one case, that of the south well in the center row of Center Avenue, the hole was finished; and, as it was not convenient to concrete at that time, was allowed to stand full of water for two or three weeks. When it was finally pumped out to be filled, it was found to have about four feet of clay, which had come down under the lagging. As this was removed, the flow of water increased, as well as the flow of clay from behind the lagging, until the hole became very dangerous to work in; so it was decided that the only way to finish it was to dig another hole alongside this one, and use it as a dump. This was done, and it worked successfully. In the greatest number of cases, the concrete could be run in chutes directly into the wells; but where this was not possible, a temporary track was laid along the center line of the row, and a 1½-cubic-yard hopper car used.

The mixture used was the same as for the abutments—that is, 1¼ barrels of cement to a cubic yard of pit-run gravel.

Columns and Cross-Girders. The columns and cross-girders erected during 1906 were of steel; but after the success attending the construction of slabs during that year, it was decided that reinforced concrete columns and cross-girders would not only be more permanent, but would be more economical as well, which was borne out as the following estimate will show (the estimate being for a 14-foot bent):

Steel column and cross-girder, 10,200 lbs., at 3.5 cents $357.00
Concrete column and cross-girder, 7.12 cubic yards, and bars at $20.00..... 142.40

The concrete construction thus costing about 40 per

cent of the figure for steel work. This result was so surprisingly low that it was checked back by several men before being taken as correct.

The lengths of span of the cross-girders are 12 and 14 feet, these lengths being taken because of the fact that the shorter spans were more economical and their lengths worked out to fit the width of the right of way.

The columns are 24 inches square, reinforced by structural steel basket of four 3½x3½x½-inch angles tied together with batten-plates about 2 feet C. to C. This basket was about 18 inches square, and was wrapped with triangular mesh of No. 12 gauge wire, the mesh being 4 inches, this giving a wrapped column. The unit-load upon the columns was 807 pounds per square inch for the center column, and 545 pounds per square inch for the side columns, considering only that area inside the steel basket. Over the total area of column, this reduced to 454 pounds and 307 pounds respectively.

The work was done as follows: The concrete in the cylinders having been purposely left below grade, the frames or baskets were placed over the center of the well, carefully centered and plumbed, then enough concrete placed around the lower part to insure their being held firmly in place; after this had set for two or three days, the column forms were set up and concreted up to the juncture with the cross-girders, which is at the springing-line of the lower curve. These column forms were made in four pieces, metal-lined, and held together by girts, having a forked end to receive the bolt, this making a very stiff form.

The mixture used was a 1:2:4 concrete of screened gravel, torpedo sand, and cement, and was mixed and placed by hand.

The cross-girders are designed as simple beams of 14- and 12-ft. span, and are 2 ft. 6 in. wide, and 4 ft. deep at the center, the curve being put in for appearance only. They were designed as simple beams, for the rea-

son that they would be built as such spans, being bulkheaded at the center line of columns at points most convenient.

The bending moments per foot width of girder are for center girder, 13,150,000 inch-pounds; for sidewalk girder, 7,468,000 inch-pounds; while the steel reinforcement is 1.3 per cent and 1 per cent respectively. The girders were designed by the use of the Johnson formula, and checked back by those of Prof. Talbot, these unit-stresses being as follows:

Center Cross-Girder—Tension in steel, 14,850 lbs. per square inch; compression, 780 lbs. per square inch.

Side Cross-Girder—Tension in steel, 15,500 lbs. per square inch; compression, 689 lbs. per square inch.

The bars over the columns were put in as a matter of precaution, and have the same area as the main bars. The web stresses in the girders are quite high; but the shear bars have sufficient area to carry all diagonal tension at 12,000 lbs. per square inch stress.

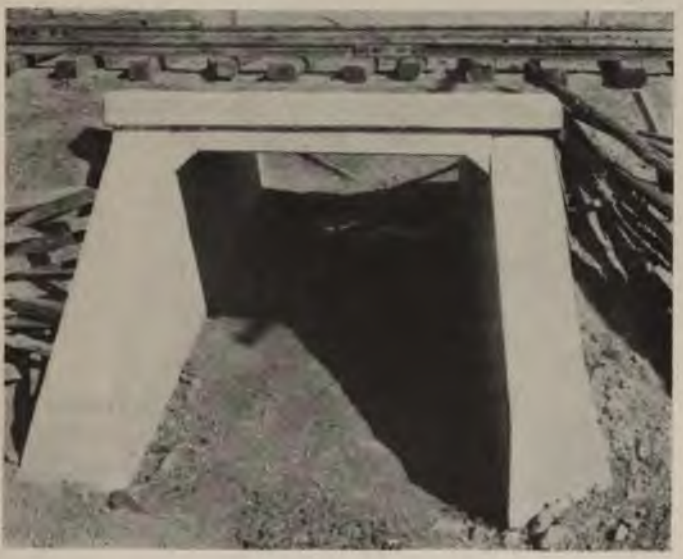
Cross-Girder Forms. The 14-foot cross-girder forms were lined with metal to give a smooth surface to the concrete, and also increase the life of the form. The mixture was a 1:2:4, mixed and placed by hand, the same materials being used as for columns.

Concrete Decks. The decks were originally designed in 1905, the live load being equivalent to about E60 Cooper's loading, plus 100 per cent. This was assumed to be distributed over 10 feet of width. In checking back, it was found that the stress in the steel was 12,750 lbs., and compression in concrete, 668 lbs., per square inch; for street slabs it was 12,700 lbs., and 659 lbs. for sidewalk slabs.

Slab Forms. A cinder foundation about 2 feet deep was laid, and upon this the mud sills were placed, being carefully tamped and leveled. The main sills resting upon the mud sills were leveled up by the use of shingle wedges.

A
CONCRETE GIRDER HIGHWAY BRIDGE, BALTIMORE COUNTY, MD.

B
CONCRETE GIRDER HIGHWAY BRIDGE, ANDERSON COUNTY, KANSAS.



C
A CATTLE-PASS.

PLATE 6—CEMENT CONSTRUCTION.

REINFORCED CONCRETE BENTS READY TO RECEIVE FLOOR-SLABS.

Track elevation work for the Illinois Central Railway Company, Chicago, Ill.

The floor consists of 2-inch tongued-and-grooved lumber, and was spiked firmly to all the sills so as to prevent warping. On the floor a template of 1-inch boards was laid, and the sides and ends erected, these being units.

The bars were taken into the form before the last end piece was placed, and arranged later on as needed. In the spacing of the bars, a small V-shaped iron or saddle was used. These were spaced near the ends, center, and quarter-points, and carried a ½-inch bar, transversely to which the main bars were wired after being carefully spaced. The wiring had to be carefully done so as to hold the bars from spreading in concreting.

The main stirrups were suspended in place and boxed in before concreting. These stirrups were made of 1⅝-inch round iron for the street slabs, and 1⅛-inch for the sidewalk slabs, and were used to engage the toggle on the derrick for erection.

The forms were given a coat of coal tar paint, consisting of coal tar, kerosene, and cement, which gave very good results and preserved the forms from checking and warping.

The mixing plant was placed opposite the slab form to be concreted, and the material placed direct by chutes, the chute being long enough to reach well back past the middle of the form, with trap doors intermediate so that material could be placed uniformly.

The first two or three batches were smaller and contained more sand than those later, this being done to simplify the working of the concrete around the reinforcement, which was not easy, the bars being only 2½-inch C. to C. for inch bars. After the lower 15 to 18 inches was in place, the work was simple, care being taken to get a well-spaded smooth surface.

The mixture used was a 1:4 concrete of pit-run gravel, which was of fairly uniform mixture. Whenever any change in uniformity was observed, a mechanical analysis

was made of the gravel, and the required material added to give a dense concrete.

Test specimens in the form of cylinders, 6 inches diameter and 9 inches long, were taken every day and stored under identical conditions with the slabs. Results showed an average crushing strength of 1,839 lbs. per square inch (60-day tests).

The side forms were removed from the slab at the end of four days, and the concrete kept damp by daily use of hose until three weeks old.

The age at which the slabs were moved to the storage piles varied with the condition of the work, the earliest being 30 days for the street slabs, and 20 days for the sidewalk slabs.

In the storage yard, the slabs were piled three high, the lower slab being placed on timbers set outside the quarter-points, and the ground dug out under the center to prevent center bending. Two cases of center bending did occur, with a result of breaking the lower slab over the back, there being no longitudinal reinforcement in the back of the slab.

The slabs built one year were for use the following year, so as to be well seasoned before being put under traffic. The slab is handled by the use of a toggle frame, consisting of four eye bars with channel strut at the lower pins; this engages the slabs by the stirrup, a pin connection being used, as it is far more reliable than a hook. The machines used were 75-ton to 100-ton wrecking cranes equipped with straight booms.

In placing the slabs, they are loaded on cars and shipped down to the work. The temporary bridge is pulled up by the derrick, and the slabs set directly ahead of the machine. This work is naturally slow, on account of the loads to be handled and the care with which the machine must be blocked up before handling the load. A good day's work is four large and two small slabs.

Plate 7 is a view of similar work done for the Illinois Central Railway Company in Chicago.

TRESTLES AND VIADUCTS

Railway Trestles. A trestle may be defined as a long bridge made up of a large number of comparatively short spans. There are over 2,000 miles of timber railway trestles in the United States. Some of these trestles will be replaced by earth embankments; but a large part of them carry the tracks over swampy land, flood plains, or city streets, and will have to be maintained indefinitely. The rapid deterioration and large fire risk of a wooden trestle make it extremely desirable to find a more permanent form of construction. A steel trestle is uneconomical for any ordinary height and not very permanent; so reinforced concrete has been suggested, tried, and proved to be satisfactory in almost every respect. At the present prices, a timber trestle is less expensive in first cost; but with the increasing cost of timber, reinforced concrete will in a comparatively short time have the advantage of cheapness, as it has now of durability, permanence, strength, and stability. In addition to these qualities, concrete trestles are free from maintenance expenses and fire risks.

Fig. 51 shows a side view, top view, and cross-section of a typical reinforced concrete railway trestle. This trestle has three spans measuring 16 feet from center to center of piers. The slabs

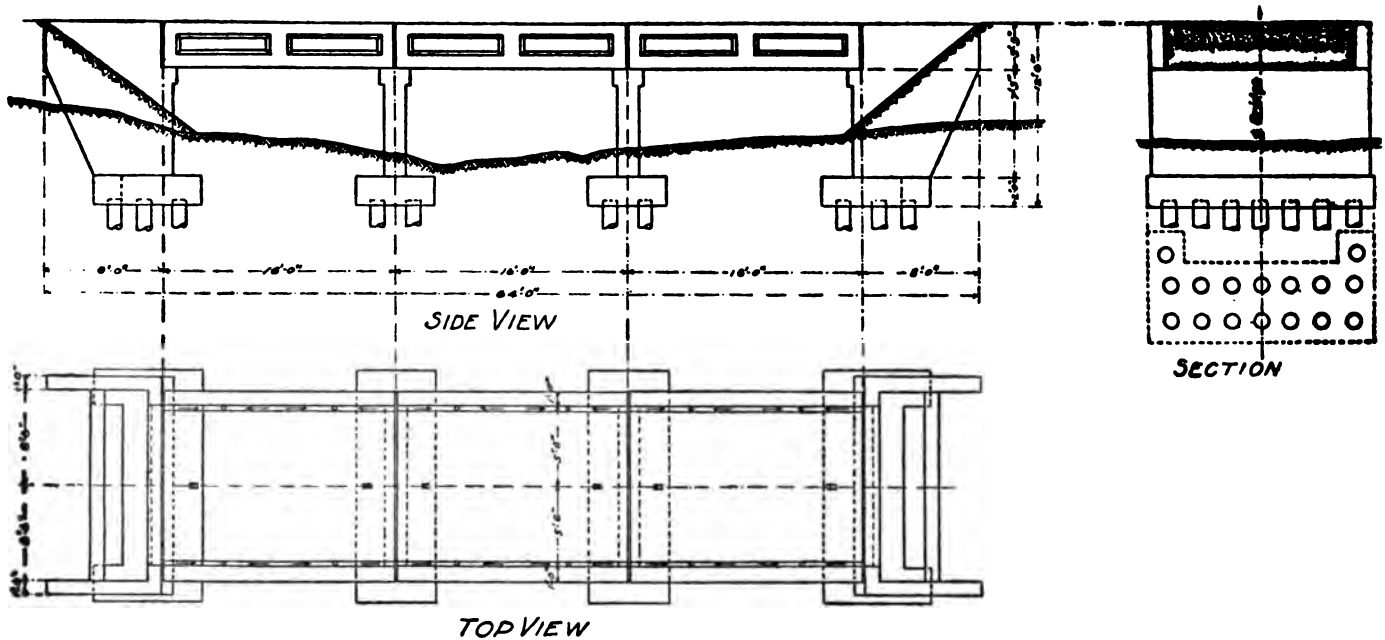


Fig. 51. Typical Reinforced Concrete Railway Trestle.

Fig. 52. Longitudinal Section of 16-Foot Slab for Railway Trestle Shown in Fig. 51.

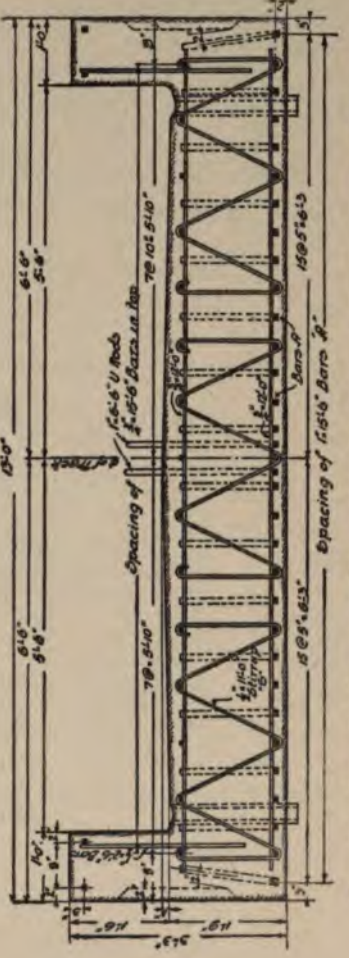


Fig. 53. Cross-Section of 16-Foot Slab for Railway Trestle Shown in Fig. 51.

are shown in detail in Figs. 52 and 53; they are 13 feet wide, by 22 inches thick.

A reinforced concrete railroad trestle with concrete pile piers is illustrated in Plate 8. This type of trestle has been found to be relatively inexpensive, and seems likely to be very extensively used. The following description refers to the trestles of this kind built by the Chicago, Burlington & Quincy Railroad:

The spans are 14, 15, or 16 ft. c. to c. of bents. Each bent consists of six concrete piles handled and driven in the same way as timber piles, supporting a cap or cross-girder which is cast in place. Upon the caps rest

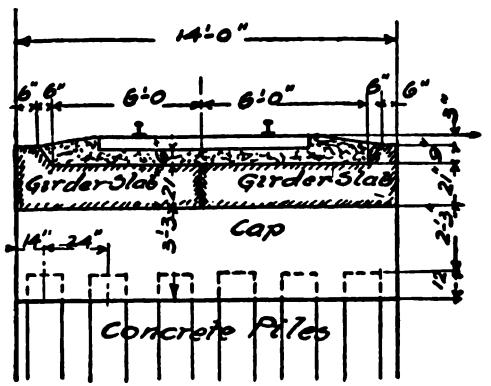


Fig. 54. Cross-Section of Concrete Pile Trestle Showing Details of Bent. See Plate 8.

the girder slabs which form the floor, each span consisting of two slabs placed side by side.

The concrete piles are of two forms: (1) rectangular cast piles; (2) Chenoweth rolled piles. The cast or moulded rectangular piles are made to the designs of the Bridge Department. They are made in lengths up to 30 ft., and most of them are not pointed, being 8 by 8 in.

at the smaller end, though some of them have points tapering to 5 by 5 in. The general design of the pile-bents and the construction of the caps, are shown in Fig. 54. The 30-ft. piles are 16 in. square at the top, with 4-in. chamfers. The reinforcement consists of eight ½-in. bars and a spiral coil of wire of varying pitch. The wire is coiled on a mandrel. When the coil is completed, it is removed and set in place in the form, the longitudinal rods being wired to it at intervals. Each 30-ft. pile contains: 1.044 cu. yds. of concrete; eight steel bars ½ in. square and 29 ft. 6 in. long; and 535 ft. of No. 12 black wire.

The Chenoweth rolled concrete pile has a reinforcement consisting of a spiral sheet of netting, with the usual longitudinal bars.

In the construction of the trestle, the piles (whether of the cast or rolled patterns) are driven by a railway pile-driver in the usual way. A cushioned cap is used in driving, and there has been very little trouble from breakage of the piles. When breakage has occurred, it has been due, as a rule, to using a pile which has not been given sufficient time for thorough setting or seasoning of the concrete.

The cost of driving is found to be a little higher for concrete piles than for wooden piles. Where possible, a water-jet has been used, making the driving of the pile very much easier and more economical.

The piles being driven, a form is built for the cap of each bent. This has a sheet-iron lining. The corners are chamfered, and the ends of the caps are rounded. The concrete is well-spaded at the sides of the form to give a smooth surface. The forms are left in place about 30 days, before the superstructure is set in place.

Each span consists of two reinforced-concrete slabs or girders, each slab forming half the width of the floor and having a curb wall to retain the ballast. Drain-holes are cored in the slabs, and steel stirrups are embedded in

them, with the loops projecting so as to give a direct attachment for chains in handling.

The concrete used for the trestles is of different composition for different parts of the work. For the piles is used a 1:3 mixture of cement and fine screened gravel, or a 1:2:3 mixture using sand and fine stone screenings. The concrete for the Chenoweth piles is made comparatively dry, while that for the cast piles is made very wet. For the caps and girders, the mixture is as follows: 1:4½ with gravel (pit or screened gravel, according to service); 1:2:4 with sand and stone. A 2-in. size is the maximum for both stone and gravel. The concrete is well spaded at the sides of the forms, in order to give a smooth surface. The quantities and weights are about as follows:

	Concrete, Cu. Yds.	Steel Bars, Lbs.	Weight, Lbs.
Single cap	4.2	712	17,500
Double cap	8.5	1,320	35,300
Girder slab,* 14-ft. span	13.6	1,421	27,200
Girder slab,* 16-ft. span	16.8	1,815	33,600

The piles are allowed to season for about 30 days, the girders for 60 days, before handling. The caps are cast in place, as already described, and are allowed to season for 30 days before the girders are placed upon them.

For structures of over five or six spans in length, longitudinal rigidity is obtained by the use of double bents at suitable intervals. The double-bent consists of two rows of piles carrying a single cap of twice the usual width. In the Salt River trestle (see Plate 8), a solid pier was used in place of the piles and cap at every sixth bent, but the double-bent construction is considered preferable. Where longer spans are used (about 25 ft.), and where the trestles cross streams in which floating ice has to be resisted, thin piers are used in preference to the pile bents. These are carried down to footings on a solid

*Each slab forms half the width of one span.

foundation, or may be supported by wooden or concrete foundation piles.

For the construction of the first of these structures, falsework was used. Wooden piles were driven at each side, in line with the old bents, and the 16-ft. stringers were swung round to form 16-ft. caps for a temporary floor or deck. This enabled the old structure to be removed entirely, and the concrete trestle built, without interference with traffic. In later work, the floor of the timber trestle is partly dismantled, and the concrete piles are driven to form bents intermediate with the old timber bents. The forms for the caps are then erected, and the concrete caps are cast in place, without interfering with traffic. This concrete is allowed to set for about 30 days. A part of the timber structure is then torn out by a wrecking crane or derrick car, and the same machine sets the concrete girder slabs in place upon the concrete caps. The track ties are supported temporarily on 6-in. blocking on the floor, ready for ballasting.

The longest structure is 435 ft. long; the maximum height, 18 ft. from ground to rail level.

Viaducts. Viaducts are long bridges, of many spans, and may be divided into two classes: (1) high structures, usually carrying railway traffic; (2) viaducts carrying a roadway or street, often with street-car tracks and sidewalks, over rivers or railroad yards. There are notable examples of both of these kinds of viaducts built entirely of reinforced concrete.

From the point of view of the concrete constructor, these structures may be distinguished according to the type of span employed—namely: **girder viaducts** and **arch viaducts.** The discussions on the design and construction of gir-

der and arch bridges already given will apply to these two kinds of viaducts, but descriptions of one or two examples will prove interesting because of the magnitude of the structures.

The Richmond and Chesapeake Bay Railway Viaduct, illustrated in Plates 9 and 10 (A) is an example of the girder type, and its design and erection form one of the most wonderful accomplishments in reinforced concrete construction in existence to-day. This viaduct is 2,800 feet long, and varies in height from 18 ft. at either end to 70 feet at the highest point.

The viaduct was designed to carry a train of cars, each 54 ft. long over all and weighing 150,000 lbs., on four-wheeled trucks placed 33 ft. c. to c. The wheels on each truck were 7 ft. on centers, and thus the nearest wheels of the adjoining cars were 14 ft. c. to c.

The design consists essentially of a system of girders of rectangular cross-section supported by towers. Each tower is made with two vertical bents, each having two columns 6 ft. 9 in. apart on centers at top, and battered 1 to 6. They are of square cross-section, and reinforced with from four to nine steel bars, the steel being placed for transverse strains only, and the concrete to take the compression. The longitudinal struts and transverse braces are all horizontal.

The spans vary in length from 23 ft. 6 in. to 67 ft. 5 in. c. to c. of bents, the longer spans being used at railway crossings and at streets which had to be crossed with a clear span. Expansion in the structure is taken care of by expansion joints placed at intervals of about 200 ft., consisting of a grooved steel plate on top of the bent, on which a planed steel plate on the bottom of the

girder slides, while a sliding toggle near top of girder prevents any tendency to turn the girder.

The concrete, of a 1:2:4 mixture, was figured for a compressive stress of 500 lbs. per square inch and shear of 50 lbs., while the steel used was given a tensile stress of 16,000 lbs.; compression, 60,000 lbs., and shear of 10,000 lbs. per square inch of cross-section. The modulus of elasticity of concrete to steel was taken as 1:12, and the percentage of steel to be less than 1.45 per cent.

The footings for the columns were first put in, having four ¾-in. rods projecting 4 ft., around which the column was built, and also a pocket left for the bottom of the column. The foundations were either hard clay or compact gravel, and were calculated for a pressure not to exceed 6,000 lbs. per square foot. As the structure was designed so that it could be readily double-tracked when necessary, the footings were made twice as large as they would have been if designed simply for a single track; and a 4-ft. stump of a column was left, on which the future double-track column will rest. When traffic justifies double tracking the viaduct, it will be easy to construct an additional girder with proper supports, on one side of the viaduct, shift the track so that it will be supported by the new girder and one of the original girders, and carry the traffic on this track during the construction of the additional girder and new track on the other side. Cored holes are provided to take care of fastening new work to the old when double tracking is begun. The footings were carried down a uniform depth of 4 ft., unless extra depth was required to get suitable foundations.

After the erection of the forms, the columns (up to the bottom of girders) and contiguous struts were poured at one continuous operation, so as to make them monolithic. Next, the girders and floor were put in in the same manner. At first it was attempted to pour columns from the top; but, owing to the difficulty of properly ramming and working the concrete through the rein-

forcing bars, this method was abandoned. The column forms were then built in a U-shape, and the fourth side built up in sections as the concrete was poured.

Dumping buckets holding 3 cu. ft., and built for this express purpose, were used in dumping into column forms. These buckets were lifted by means of a traveling single-boom derrick seated on top of the viaduct, and a hoisting engine. The struts were poured from wheelbarrows from the top of the structure, through a 10-in. hinged pipe of galvanized iron. Concrete for the girders and floor was hoisted on wheelbarrows by double-cage towers, to the top of the viaduct, and wheeled to position on runways on the forms.

The forms were made of 2-in. lumber, dressed on one side, and as much of the lumber as possible was cleaned and used again after forms were pulled down. The forms on the sides of the girders were removed at the end of a week, but those on the columns and the supporting falsework of the girders were left in place 30 days or longer if the lumber was not needed.

The smaller girder forms were supported by falsework, consisting of 4x4-in. pieces placed 3 ft. on centers along the viaduct and resting on planking placed on the ground, which had been leveled to firm bearing. Under the heavier girder forms, at street crossings, the falsework was made of 6x6-in. timbers and the struts were supported by 4x4-in. pieces, placed at distances to suit the weight carried. Owing to the great height of the structure throughout a considerable part of its length, a prodigious amount of lumber was used in the forms and shoring. Approximately 456,000 ft. B. M. was used in the entire job, or about 16,500 ft. B. M. to each 100 cu. yds. of concrete. Of course, at street and railway crossings, special provision had to be made to carry the great weight of the girders. It is notable that in spite of the great weight of these girders, being considerably in ex-

cess of 50 tons each, the forms were erected and concrete put in place without delaying a train or street-car.

The stone used was granite, crushed so that all would pass through a one-inch ring, and was thoroughly screened.

The concrete in the footings was made of a mixture of one part cement, three of sand, and six of stone, except that in wet pits more cement was added. In all the rest of the work, a 1:2:4 mixture was used. This was made quite wet, and the concrete was thoroughly worked into the reinforcement with spades and rammers. No concrete was allowed to go in that had stood as long as fifteen minutes.

The Nelson St. Viaduct, Atlanta, Ga., illustrated in Plate 10 (**B**), is an example of an arch viaduct carrying a roadway. It crosses the tracks of the Southern Railway.

The total length of the structure between abutments, 479 feet 3½ inches, is divided into ten spans varying in length from 20 to 75 ft. The roadway carried is 32 feet wide from curb to curb, and sidewalks 9 feet wide are cantilevered out on each side. The roadway is paved with wood blocks on a concrete base. The sidewalks have a granitoid surface laid directly on the concrete. Each of the 10 spans is carried by 4 arch-ribs, 5 feet on center under the street-car tracks; and 2 outside ribs, one under each curb. The roadway ribs are designed to carry 100 pounds per square foot or a 15-ton road roller in motion. The track ribs are designed for a succession of 40-ton electric cars.

The beauty of the structure is very striking. It is not obtained by the use of highly ornamental work requiring difficultly moulded features, but lies in the simple and graceful general

proportions. All of this is obtained without extra expense, as the effect is produced by the artistic arrangement of material rather than by extravagant embellishments.

An Ocean Viaduct. One of the most wonderful feats of modern railroad engineering is the extension of the Florida East Coast Railway to Key West. The track is carried from key to key on a viaduct which consists of about 500 reinforced concrete segmental and semicircular arches of from 45 to 60 feet span, and has an entire length of about six miles. This distance is divided into four parts, there being a viaduct two miles in length between Long and Conch Keys, known as the Long Key-Conch Key viaduct (Plate 11); a viaduct between Knights Key and Pigeon Key, about 7,800 feet long, known as Knights Key Channel viaduct; a third structure known as the Moser Channel viaduct, just south of Pigeon Key, about 7,300 feet long; and the fourth, known as the Bahia Honda Harbor viaduct, about 4,950 feet long and composed of 60-foot arches.

Approximately the following quantities of material will be required in the construction of these viaducts: 300,000 barrels of cement, 225,000 cu. yd. of sand, 200,000 cu. yd. of crushed stone and gravel, and about 5,000 tons of steel reinforcing bars. The piers for these viaducts are constructed in from 6 to 30 ft. of water on very hard but porous lime rock and coral, which is overlaid with sand.

The cross-section through the center of one of the arches, Fig. 55, shows the typical design that has been employed. The arches are 15 ft. wide at the crown, allowing sufficient width for a

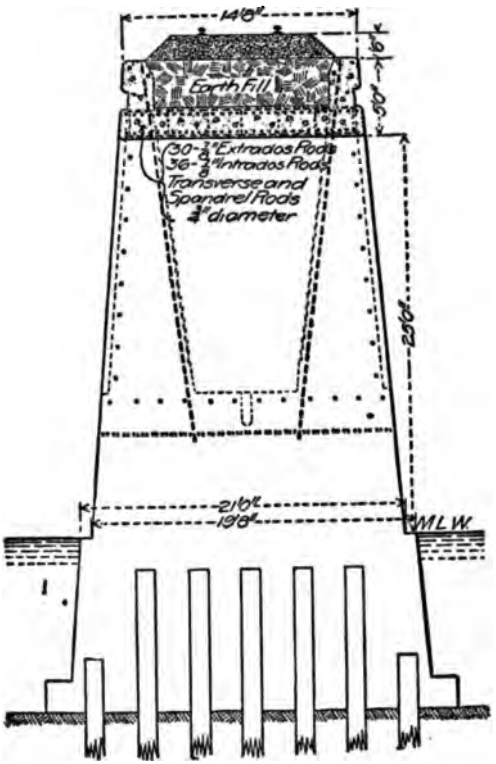


Fig. 55. Section of Ocean Viaduct at Center of Arch. See Plate 11.

single standard-gauge railroad track. The sides are battered at the rate of 1 in. to the foot of height. The rails of the track carried by the structure are about 31 ft. above mean low water.

The piers are about 21 ft. long, and 7 to 12 ft. in width. Every fifth pier, being considerably wider than the other piers, is an abutment. The arch-rings are 2 ft. thick at the crown, and about 4.5 ft. thick at the top of the pier. The spandrel walls are about 18 in. thick at the top, 3 ft. above the crown of the arch, and batter down 1 in. in 12 in. on the outside, and 1½ in. in 12 in. on the inside, making the width about 5.5 ft. on the top of the pier. There are about nine tons of ⅝ and ¾-inch twisted steel bars in each complete arch.

REINFORCED CONCRETE CULVERTS

The difference between a culvert and a bridge is not very clearly marked; a large culvert may be called a small bridge, and a small bridge is but little different from a culvert. The two structures may best be distinguished by their purpose; a bridge is intended as a crossing over a stream or gulch, while a culvert is needed to allow a creek or ditch to pass under a road. A culvert serves as a drain or conduit, and is covered by the road embankment; for this reason it must be composed of a material which will not rot under the most adverse conditions of alternate wet and dry periods. Bridges are often built of considerable lengths when an embankment with a small culvert would be much more desirable because of the greater stability and permanence of the crossing and the reduced cost of repairs and renewals.

REINFORCED CONCRETE TRESTLE OVER SALT RIVER, C., B. & Q. R. R.

This bridge is supported by reinforced concrete piles, 22 feet long, driven with a 3,000-pound hammer. The spans are 14 feet center to center, and the average height is 10 feet; total length, 477 feet 6 inches.

FALSEWORK FOR THE RICHMOND & CHESAPEAKE BAY RAILWAY REINFORCED CONCRETE VIADUCT.

PLATE 9—CEMENT CONSTRUCTION.

There are three distinct types of culverts: **Box-culverts,** which are rectangular in section; **arch culverts,** which have arched tops and in some cases arched floors; and **pipe culverts,**

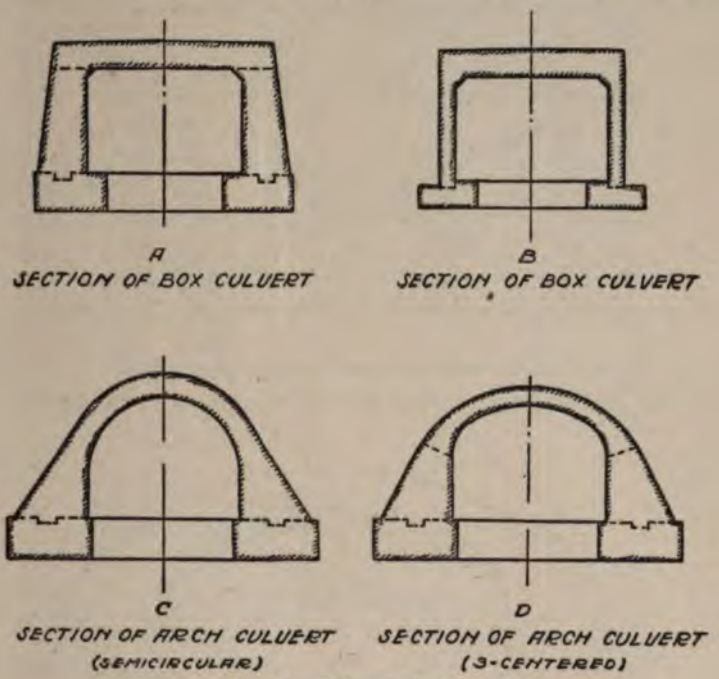


Fig. 56. Culvert Sections.

which are circular or elliptical in section.

Box culverts (see Fig. 56, **A** and **B**, and Fig. 57) were formerly built of wood or stone, and later of concrete, with covers of old rails; but reinforced concrete is now the standard construction. Arch culverts (see Fig. 56, **C** and **D**, and Fig. 58) are built of concrete, either plain

or reinforced, the more modern material having replaced stone masonry.

Culvert pipes of cast iron and clay products are still used, but concrete has invaded this field

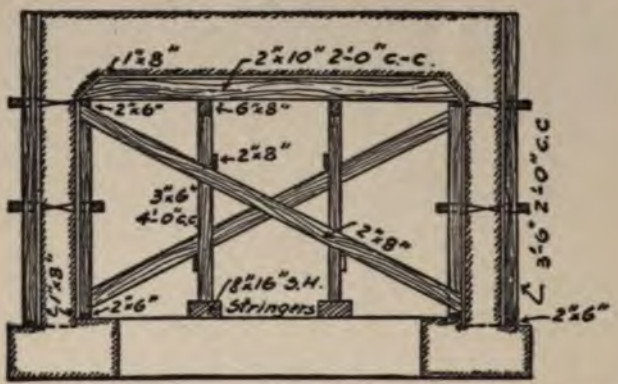


Fig. 57. Section of Concrete Box Culvert, Showing Forms.

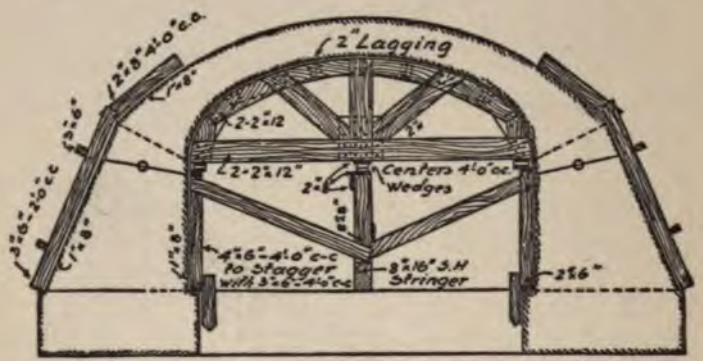
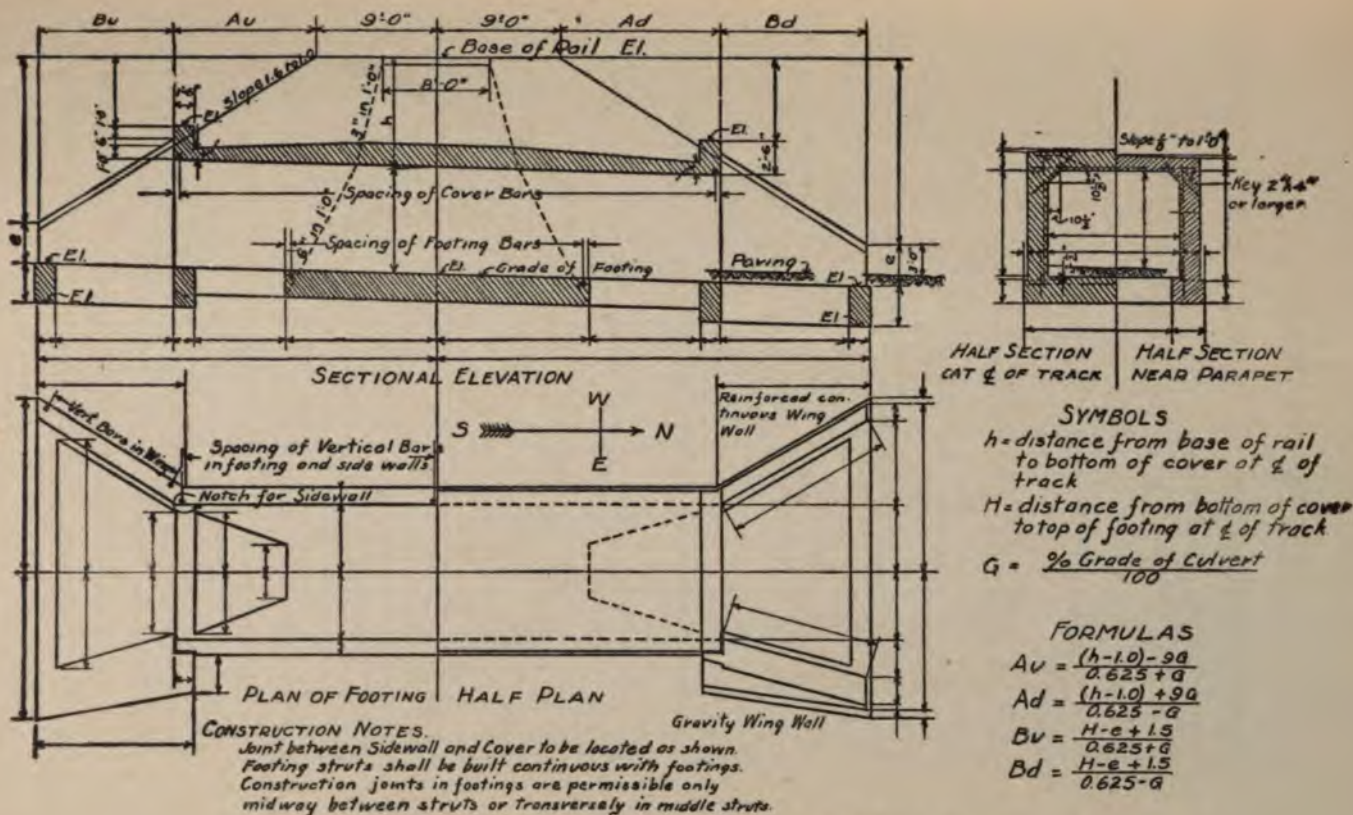


Fig. 58. Cross-Section of Concrete Arch Culvert, Showing Forms.

also, and it will probably surpersede the other materials.

Fig. 59 shows an outline plan for a standard railway culvert. Fig. 60 and Fig. 61 contain



SYMBOLS

h = distance from base of rail to bottom of cover at ℄ of track

H = distance from bottom of cover to top of footing at ℄ of track

$G = \frac{\%\ \text{Grade of Culvert}}{100}$

FORMULAS

$Av = \frac{(h-1.0)-9G}{0.625+G}$

$Ad = \frac{(h-1.0)+9G}{0.625-G}$

$Bv = \frac{H-e+1.5}{0.625+G}$

$Bd = \frac{H-e+1.5}{0.625-G}$

CONSTRUCTION NOTES.

Joint between Sidewall and Cover to be located as shown.
Footing struts shall be built continuous with footings.
Construction joints in footings are permissible only midway between struts or transversely in middle struts.

Fig. 59. General Details of Standard Concrete Railway Culvert.

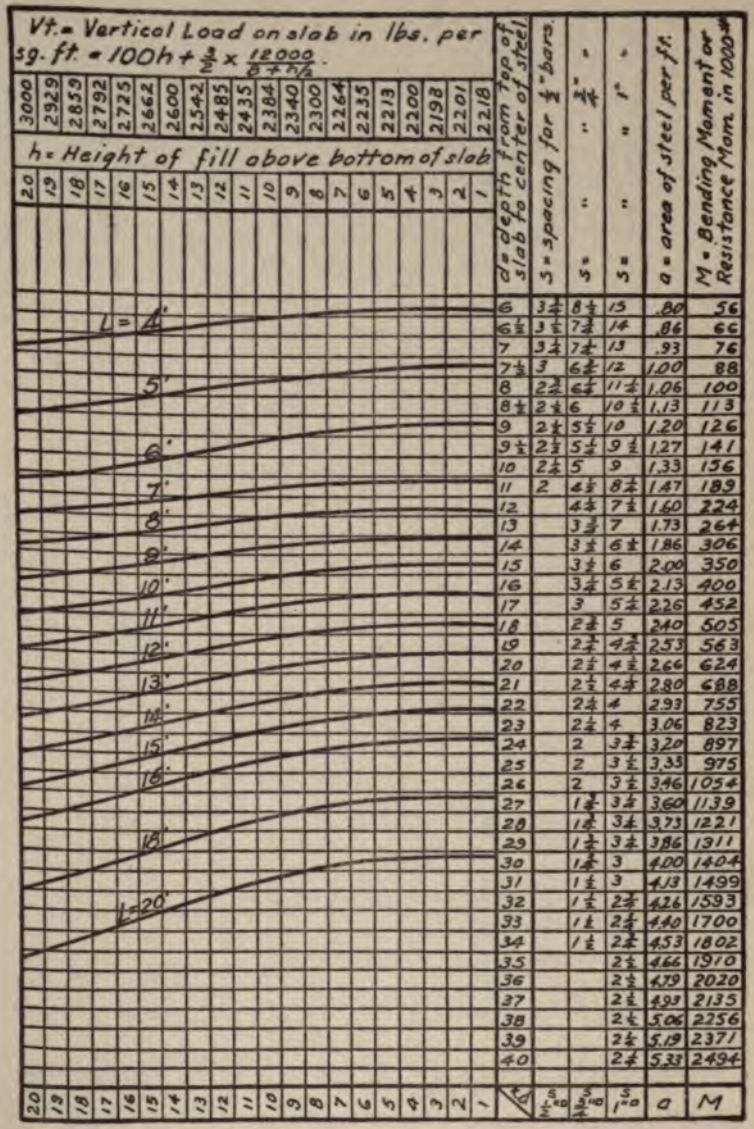


Fig. 60. Curves for the Design of Reinforced Concrete Culvert Tops.

curves for the design of culvert tops and side walls, for various spans and lengths of fill.

The curves in Fig. 60 give the thickness,

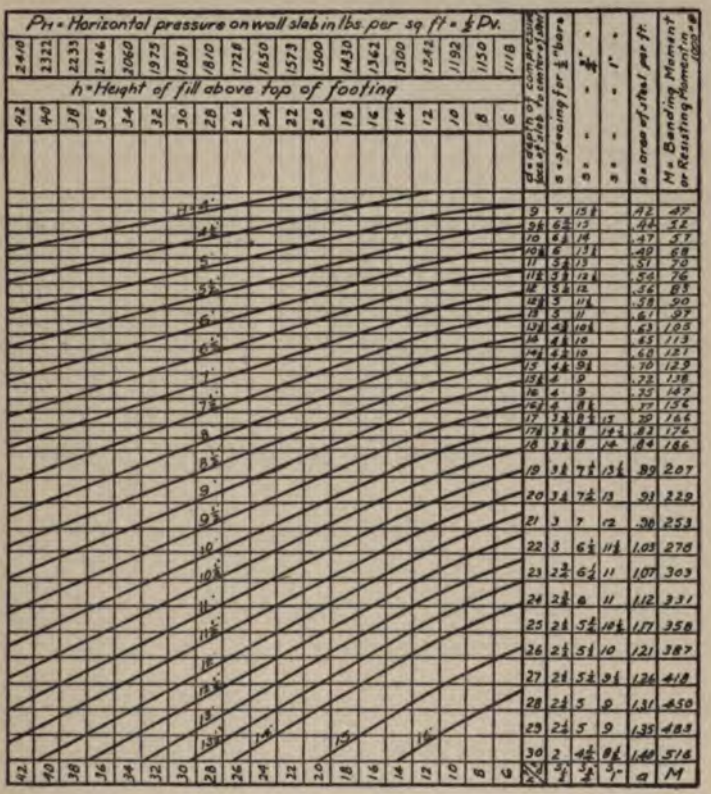

Pн = Horizontal pressure on wall slab in lbs. per sq. ft. = ½ Pv.
h = Height of fill above top of footing
d = depth of slab to centre of bar
s = spacing for ½" bars
M = Bending Moment or Resisting Moment in

Fig. 61. Curves for the Design of Reinforced Concrete Culvert Walls.

amount of steel, size and spacing of reinforcing bars, and other information for designing the cover of culverts of various spans under various heights of fill. The method of using these curves is very simple. The height of fill, or dis-

tance from the top of the culvert to the track, is read on the top or bottom border of the plate, and the vertical line is followed to an intersection marked with the required span-length; from this intersection, the horizontal line is followed to the right, and in the first column, the depth of the slab is given. The second, third, and fourth columns give the spacing of the reinforcing bars for three sizes respectively, ½, ¾, and 1 inch square. The fifth and sixth columns explain themselves.

The curves in Fig. 61 give the required thickness and reinforcement for the side walls of culverts; and they are used in the same way as the curves for culvert covers in Fig. 60. Plate 12 (**A** and **B**) shows views of typical railway culverts.

The following general instructions for the design of railway culverts are intended to supplement the outline drawing, Fig. 59 and the curves in Fig. 60 and Fig. 61.

RULES FOR THE DESIGN OF RAILWAY CULVERTS

Views. In general the following views shall be shown:

A longitudinal sectional elevation along center line of culvert.

A complete plan of culvert.

A complete plan of footings.

A half cross-section at center line of track and at parapet.

An end view.

In detailing these views, the outline in Fig. 59 shall be followed in a general way.

Size. In giving the sizes of culverts, the width shall be named first, and then the height; for example, 12x8′ indicate a twelve-foot width and an eight-foot height. By the height is meant the distance from top of paving to bottom of cover.

Footings and Struts. Wherever the bearing on the soil makes it necessary, solid floors shall be used. Solid floors should be avoided wherever possible, by extending the footings under the side walls.

Cross-struts at intervals of about ten feet shall be provided.

In general, the end struts and the footings under the wing walls shall be carried lower than the footings under the culvert barrel.

Joints. Transverse vertical joints shall be provided in culvert barrels about every forty feet.

Wing Walls. Wing walls under about 8 feet in height shall be made continuous with culvert walls. (See 30° wing, Fig. 62.)

Wing walls higher than about 8 feet shall be made self-supporting, and a joint shall be provided between the wing and culvert barrel.

Longitudinal Steel. Longitudinal steel reinforcement of a sectional area about 1/750 of the concrete section shall be provided in culvert barrels.

Culverts under Low Fills. Where the distance from base of rail to bottom of cover is less than 3 ft. 6 in., the typical plan in Fig. 59 shall be modified. The distance from C.L. of track to face of parapet shall be made 8 ft. 6 in., and top of parapet shall be made 6 in. below base of rail.

Thickness of Cover. The thickness of the cover shall be decreased, and the amount of steel diminished, from the edge of the live load spread to the parapet.

Skew Culverts. In skew culverts, the cover shall be

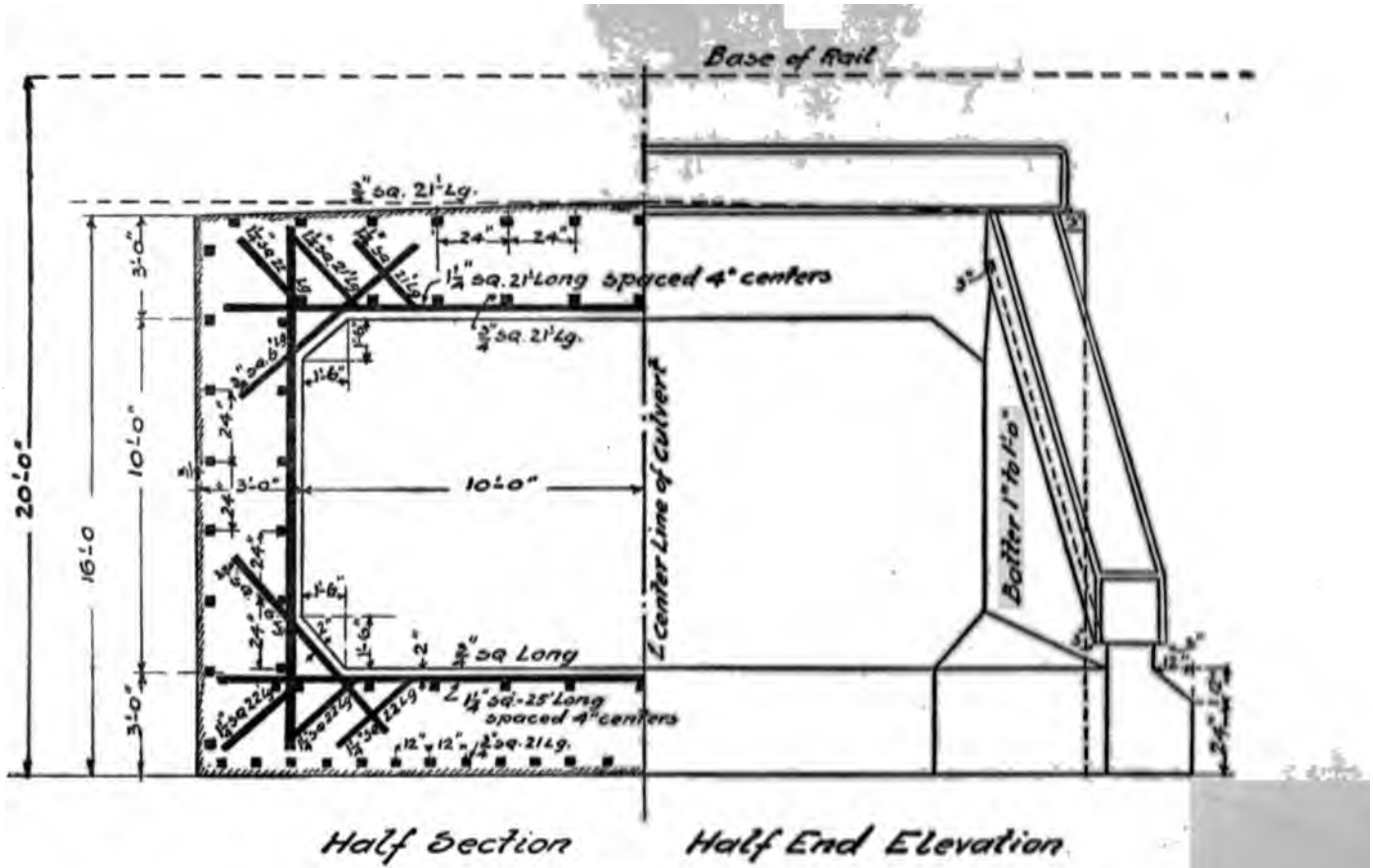
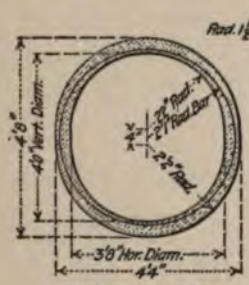


Fig. 62. Details of 20-Foot Culvert Shown in Plate 13 (B).

designed for the span in the direction parallel to the track, and the bars shall be placed in this direction.

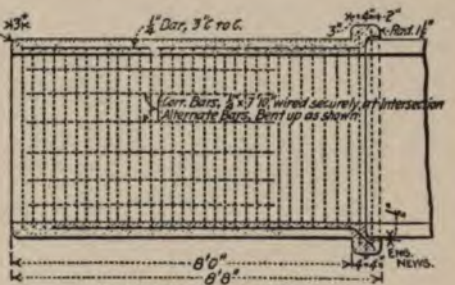
Reinforced Concrete Culvert Pipe. Plate 13 (**A**) illustrates the sectional concrete culvert pipe now being used in many cases instead of iron pipe. The sections are made 6 or 8 feet long so that they may be easily handled. The bell and spigot ends (Figs. 63 and 64) provide a good and flexible means of connection, but are expensive to construct; and tapered ends, as in Figs. 65 and 66, are more often used.

Table II shows the comparative weights and cost of concrete and cast-iron pipes from 1 ft. up to 4 ft. diameter; it is based on the price of $7 per cu. yd. for concrete, and 3¼ cts. per lb. for cast-iron pipes. The thicknesses for concrete pipes of various diameters have been taken



Cross Section.

Fig. 63.



Longitudinal Section.

Fig. 64.

Sectional Reinforced Concrete Culvert Pipe Used by Chicago, Burlington & Quincy Railway.

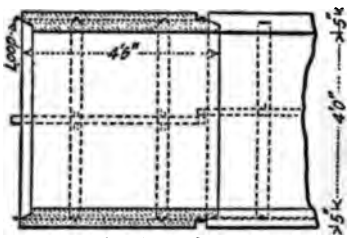
as approximately proportional to the thickness of cast-iron pipes of the same diameter, the 4-ft. pipes being used as a basis for calculation.

TABLE II

Relative Thickness, Weight, and Cost of Cast-Iron Pipe and Concrete Pipe

Size and Kind of Pipe	Thickness	Weight per Lin. Ft.	Cost per Lin. Ft.
12-in., cast-iron	0. 33/64 In.	75 Lbs.	$ 2.44
concrete	2.0 "	88 "	0.16
18-in., cast-iron	0. 47/64 "	167 "	5.43
concrete	3.0 "	220 "	0.36
24-in., cast-iron	1.0 "	250 "	8.13
concrete	4 1/2 "	420 "	0.68
30-in., cast-iron	1 1/16 "	334 "	10.86
concrete	4 1/2 "	602 "	0.88
36-in., cast-iron	1 1/2 "	450 "	14.63
concrete	4 1/2 "	676 "	1.10
42-in., cast-iron	1 1/2 "	600 "	19.50
concrete	5 1/2 "	960 "	1.55
48-in., cast-iron	1 7/16 "	725 "	23.56
concrete	6.0 "	1,131 "	1.83

The first cost of concrete pipes at the place of manufacture would, according to the table, be less than $^1/_{12}$th of the cost of cast-iron pipes. The cost of transportation and of installing the concrete pipes would, on account of the greater weight and greater number of pieces, probably be very nearly double the cost for cast-iron pipes. On account of the lack of reliable data regarding this cost, it is very difficult to give a



Longitudinal Section.

Fig. 65.

Cross-Section.

Fig. 66.

Sectional Concrete Pipe with Tapered Ends.

fair comparative estimate of the cost of the two styles of culverts in place. However, since

transportation and installation of iron pipes is but a small proportion of the cost of the completed culverts, it is evident that the cost of a concrete pipe culvert in place would be but a small fraction of the cost of a cast-iron pipe culvert of the same diameter, provided the pipes were hauled only moderate distances.

ABUTMENTS AND PIERS

Design of Abutments. The supports at each end of a bridge are known as **abutments.** An abutment serves a number of purposes: it furnishes a resting-place for the end of the span; it distributes the weight of the bridge over the foundation; and it prevents the bank from running out into the stream at the end of the bridge.

It is the object of bridge engineers to plan abutments which will fulfil these requirements and at the same time be as economical as possible to construct; and every man who may be called upon to assist in bridge-building should understand this object if he expects to do his part of the work intelligently.

The first step in the design of an abutment is to provide a resting-place for the **pedestals** which carry the bridge-span. These pedestals are made sufficiently large to prevent the crushing of the material of the top of the abutment, or bridge-seat, under the load of the bridge. After the size of the bridge-seat has been determined, the area and depth of the **foundation course** is calculated, the actual dimensions depending on

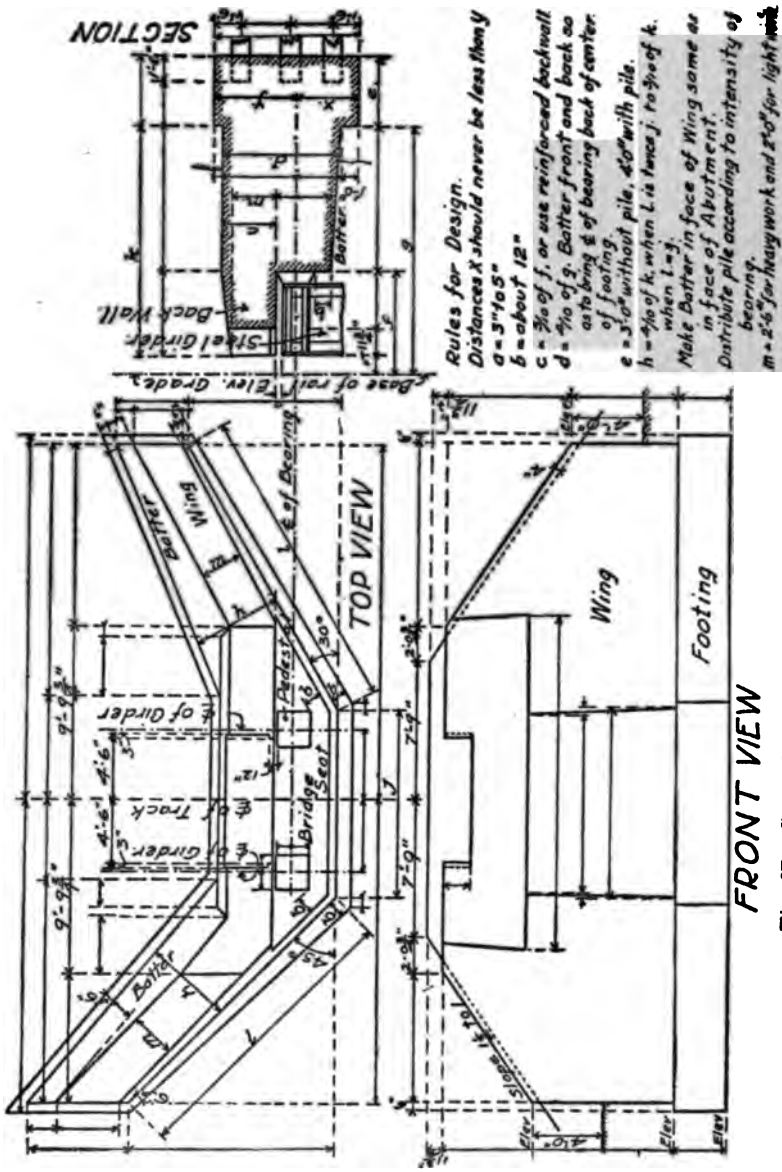

SECTION
Back Wall
Steel Girder
Base of rail
Elev. Grades
Batter
TOP VIEW
Wing
Batter
L.E. of Bearing
Pedestal
Bridge Seat
C. of Girder
C. of Track
Batter
Wing
Footing
FRONT VIEW
Rules for Design.
Distances x should never be less than y
a = 3"+05"
b = about 12"
c = 3/10 of f, or use reinforced backwall
d = 4/10 of g. Batter front and back so as to bring ℄ of bearing back of center of footing.
e = 3'-0" without pile, 4'-0" with pile.
h = 4/10 of k, when L is twice j. h=3/10 of k, when L=j.
Make Batter in face of Wing same as in face of Abutment.
Distribute pile according to intensity of bearing.
m = 2'-6" for heavy work and 2'-0" for light work

Fig. 67. General Details of Standard Concrete Railroad Abutment.

the nature of the underlying soil, which is known from preliminary investigations. The third and last step is to provide for the **embankment** behind the abutment in such a way that it will not encroach on the clear waterway or opening under the span. There have been a number of abutment types developed to accomplish this object, among which are: **wing-abutments, Tee-abutments, U-abutments, arch abutments,** and a number of special types.

Wing-Abutments. For the average size of bridge and height of abutment, wing-abutments are the most generally used, and are probably the best. Concrete has replaced stone masonry as the material for constructing such abutments, and answers the purpose excellently. Wing-abutments are so called because of the two sloping walls which extend out from the sides to the full width of the embankment to prevent the earth from running into the stream. These walls are known as **wing-walls.** The entire abutment, including the wing-walls, must be designed to retain the earth behind it according to the principles set forth below in the discussion of "Retaining Walls."

Fig. 67 is a plan of a typical railroad abutment of concrete. A top view, front view, and section are shown, and the technical names of the most important features are marked. The dimensions given are subject to some variation, on account of the differences in the standard embankments of the various railways. The in-

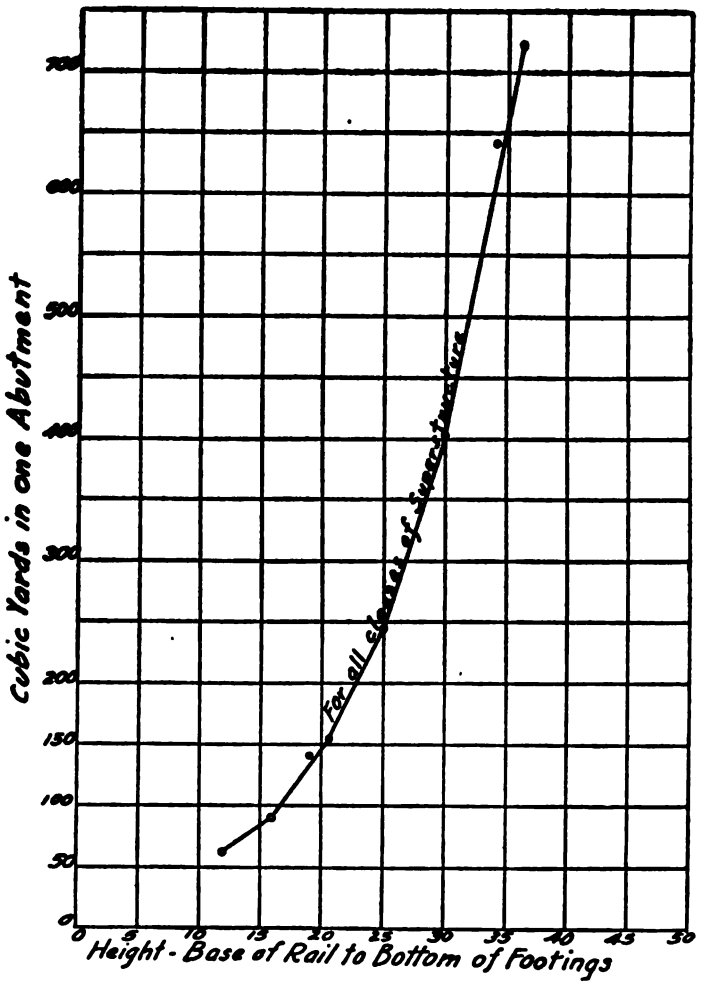
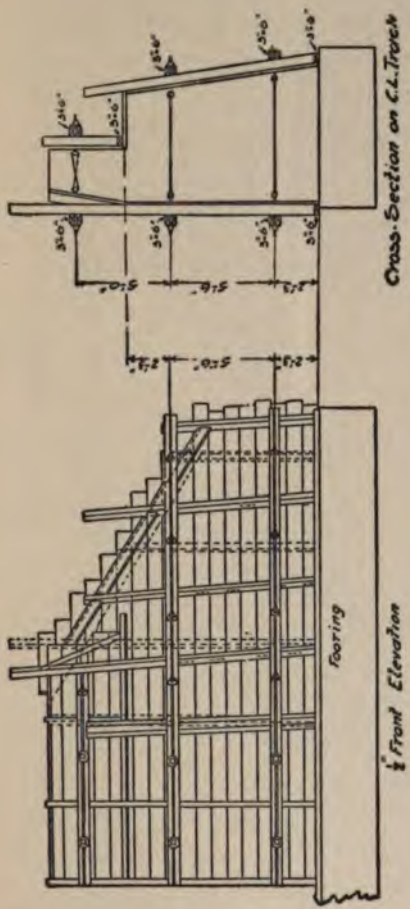


Fig. 68. Volumes of Concrete Wing Abutments.

structions headed "Rules for Design" (Fig. 67), will enable one to fill out the more important dimensions marked with letters on the drawing. All the blank dimensions shown will have to be



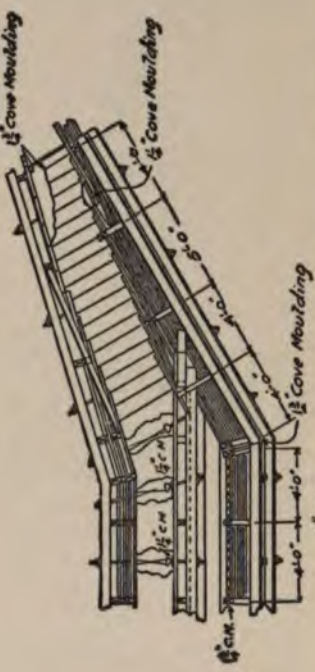


Fig. 69. Forms for Concrete Wing Abutments.

figured from these fundamental dimensions, and filled in. When all the distances indicated are given, the form-builder will have sufficient information to construct the form work, which should present no especial difficulties after the footings are finished (see Fig. 69). It will be noted that one of the wings of the abutment in

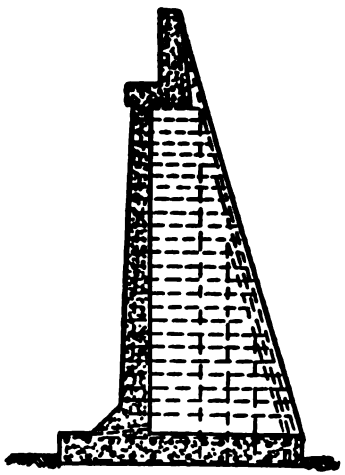


Fig. 70. Section of Wing Abutment Shown in Plate 13 (B).

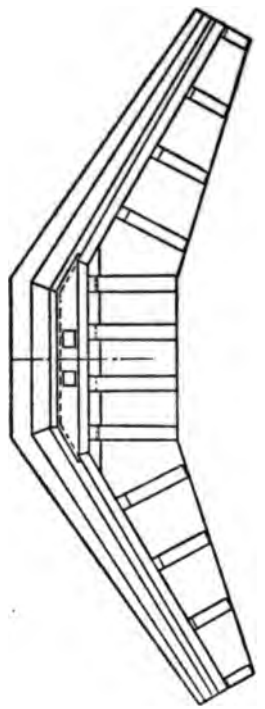


Fig. 71. Plan of Wing Abutment Shown in Plate 13 (B).

Fig. 67 is at a different angle from the other; this angle will have to be decided on for each wing for each abutment, according to the circumstances of the case—namely, the direction

A
REINFORCED CONCRETE VIADUCT FOR RICHMOND & CHESAPEAKE BAY RAILWAY.

B
NELSON STREET VIADUCT, ATLANTA, GA.

Roadway, 32 ft.; two 9-ft. sidewalks; ten arch spans of from 20 to 75 feet.

Portion of completed viaduct.

Viaduct under construction, showing arch forms.

REINFORCED CONCRETE ARCH VIADUCT OVER FLORIDA KEYS.

Key West Extension of Florida East Coast Railway.

of the stream and current at the bridge; the condition of the stream bed, the shores, and the embankment; the strength of current; the elevation of high water; and the possible shifting of the stream.

Highway abutments of the wing-type are designed and constructed along exactly the same lines as railroad abutments, but they are usually smaller.

When wing abutments exceed a height of about 25 feet, it has been found economical to reduce the mass by introducing thin counterforts, and reinforcing the entire structure to tie it together. Such an abutment is shown in Plate 13 (**B**) and in Figs. 70 and 71.

Special Abutments. For bridges over streams or valleys with high, steep banks, the plain or even reinforced concrete wing abutments become uneconomical, on account of the large yardage they require to give them sufficient weight and stability to prevent overturning. Each one of these high abutments is a special problem which must be studied in order to find the cheapest type of structure to fit it; but there are a number of distinctive schemes which may best be illustrated by describing actual examples.

An interesting design of bridge abutment, of **T-section,** is illustrated in Fig. 72, the purpose of which is to effect an economy in concrete and in cost of forms as compared with the ordinary double-wall abutment of U-section. It has been

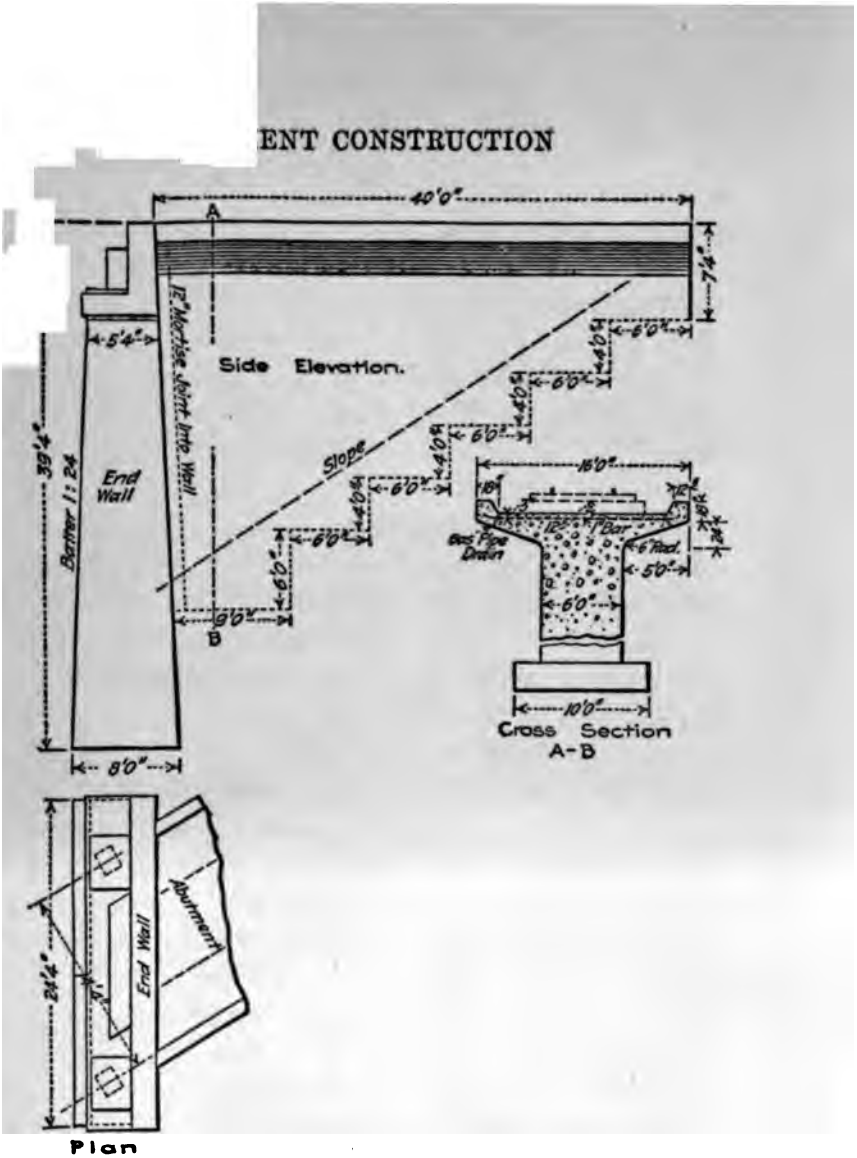


Fig. 72. A Concrete Bridge Abutment of T-Section. South Bend & Southern Michigan Railway.

used in the north abutment of the bridge carrying the South Bend & Southern Michigan Ry. (an electric interurban line) over the St. Joseph River near Berrien Springs, Mich., where the

conditions were favorable; and it was adopted on the score of economy. The foundation was hardpan, very hard to excavate, and the stepping-up of the footings for the stem of the T was readily formed in this material. The height is about 40 ft.; and by the ordinary formulas for a retaining wall, it would have required about twice the thickness of wall used, while the wings would have been heavy and the footings overlapped. It will be seen that, instead of two side walls, there is a single wall 6 ft. thick, carrying a cantilevered slab 16 ft. wide, this slab or floor being reinforced by steel bars and provided with drainage holes so as to keep the ballast in good condition.

A **U-abutment** is so called because it is shaped like the letter U. The bottom of the U is represented by the bridge-seat, and the sides of the U are represented by the two tail-walls, or retaining walls, which retain the embankment. These walls may be of massive plain concrete entirely independent of each other, or they may be thin reinforced walls tied together. The abutment of the highway crossing shown in Fig. 46 is of the latter type.

Arch abutments are used for very high abutments, such as those of the bridge over the Mississippi at Thebes, Ill. They are of different styles and arrangement. A common type is shown in Plate 5; the two small approach arches are partially covered by the fill, and serve as abutments for the middle span.

A special type of **hollow abutment** is shown in Fig. 39, for the abutment of the Sangamon river arch bridge.

Bridge Piers. It has always been the endeavor of bridge-builders to make the clear span of their structures as large as possible; but since the cost of a bridge increases very rapidly as the span is made longer, it is customary to cross only the smaller streams and valleys without the use of intermediate supports between abutments. When a bridge is supported at some point between the abutments, the supporting structure is known as a **bridge pier** or **tower.** Towers are used only for high viaducts and short spans, and are seldom placed in mid-stream; piers are far more common.

From its definition it will be seen that a pier has to carry the vertical weight of the bridge and its traffic; it usually is placed in mid-stream, and must be able to resist the action of moving water and ice, and it must give the bridge an anchorage to prevent its overturning as a result of wind or vibration. To accomplish these ends, a pier must have compressive strength, massiveness, and weight, and be designed for stability and bearing power. The civil engineer has these objects in view when he is planning the piers for a particular bridge, and a knowledge of his methods, as well as of the ways and means of getting the required results, should be of value to the construction man who carries out the work in the field.

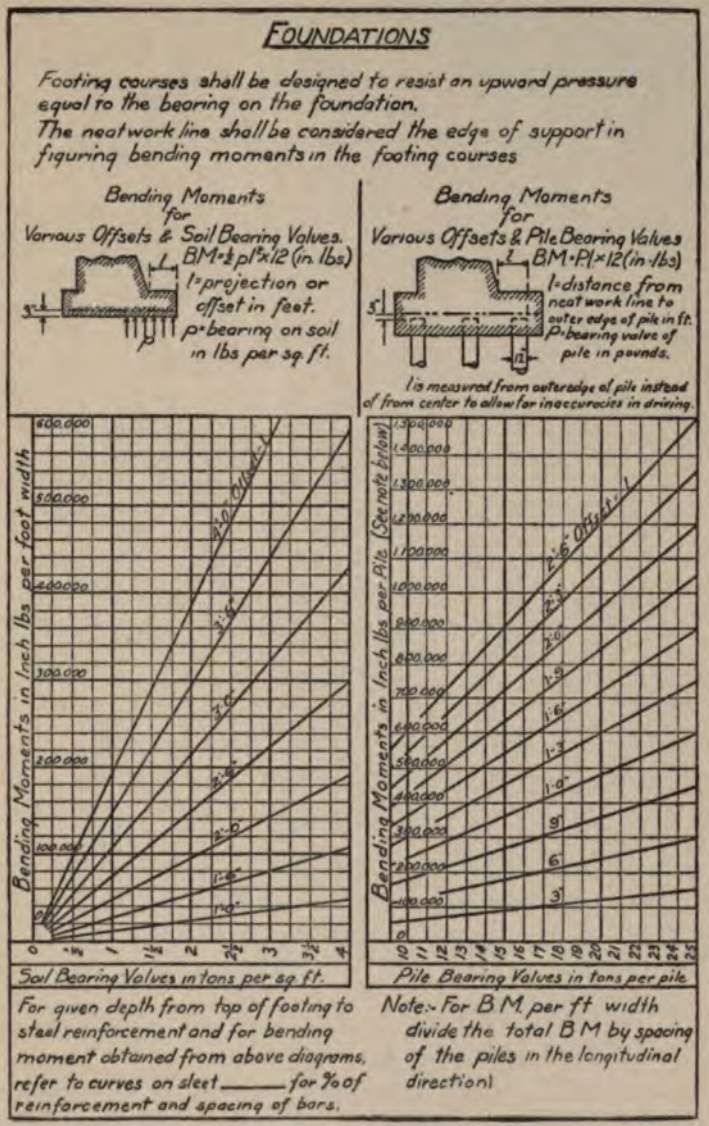

FOUNDATIONS
Footing courses shall be designed to resist an upward pressure equal to the bearing on the foundation.
The neat work line shall be considered the edge of support in figuring bending moments in the footing courses
Bending Moments for Various Offsets & Soil Bearing Values.
BM = ½ pl² x 12 (in. lbs)
l = projection or offset in feet.
p = bearing on soil in lbs per sq. ft.
Bending Moments for Various Offsets & Pile Bearing Values
BM = Pl x 12 (in. lbs)
l = distance from neat work line to outer edge of pile in ft.
P = bearing valve of pile in pounds.
l is measured from outeredge of pile instead of from center to allow for inaccuracies in driving.
Bending Moments in Inch lbs per foot width
Soil Bearing Valves in tons per sq. ft.
Bending Moments in Inch lbs per Pile (See note below)
Pile Bearing Valves in tons per pile
For given depth from top of footing to steel reinforcement and for bending moment obtained from above diagrams, refer to curves on sheet ____ for % of reinforcement and spacing of bars.
Note:- For B M per ft width divide the total B M by spacing of the piles in the longitudinal direction)

Fig. 73. Curves for the Design of Reinforced Concrete Foundations.

The first problem—to design the pier with sufficient compressive strength and footing area to transmit the load to the foundation and spread it sufficiently to prevent settlement—is attacked as follows:

The part of the total weight of the bridge superstructure — trusses, girders, bracing, floor, etc., as well as the load of the trains, cars, vehicles, and people, which can possibly come on the piers—is computed. The steel or cast-iron **shoes** or **pedestals** which rest on the top of the pier are then made large enough to distribute this load so as not to exceed the safe compressive strength of the material of which the pier is constructed. The size of the top of the pier—or the **bridge-seat,** as it is technically known—is governed by the size and position of these bridge pedestals. The dimensions of the pier are usually increased from the top downward, by sloping or "battering" the sides until the top of the footing course is reached. **Footing course** is the name given to the lowest part of the structure, and is the layer of masonry resting directly on the foundation. The bottom of the pier must be placed at such a depth below the surface of the ground or bed of the stream as will insure a firm foundation and safety from the effects of frost and the scouring action of the current.

The total weight of the bridge coming on the bridge-seat, together with the weight of the pier itself, constitute the total load on the foundation; and the area of the base of the pier must be made

large enough to distribute this pressure according to the safe supporting power of the particular foundation. The nature of the foundation is

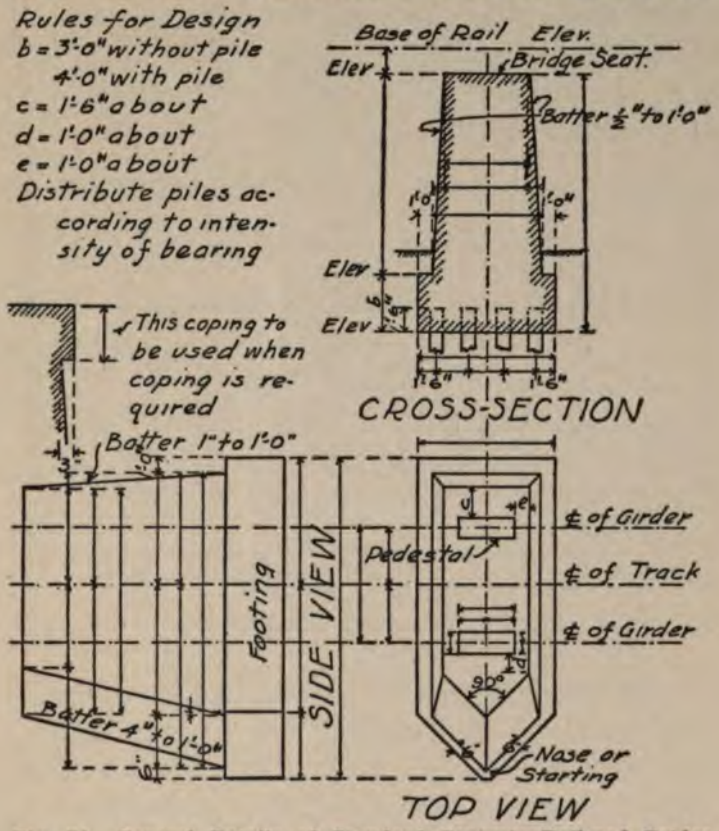


Fig. 74. General Details of Standard Concrete Railroad Bridge Pier.

ascertained before the design is made, and the supporting power in tons per square foot is estimated. In many cases it is found necessary to use piles or more extreme precautions to give the pier a sufficiently firm foundation.

The second requirement for the design of a ier is that it should be able to resist the action running water or moving ice and debris. ter will have little effect on a masonry pier ss it manages to undermine the footings; and s will not occur if the precautions mentioned he preceding paragraph are taken. Floating

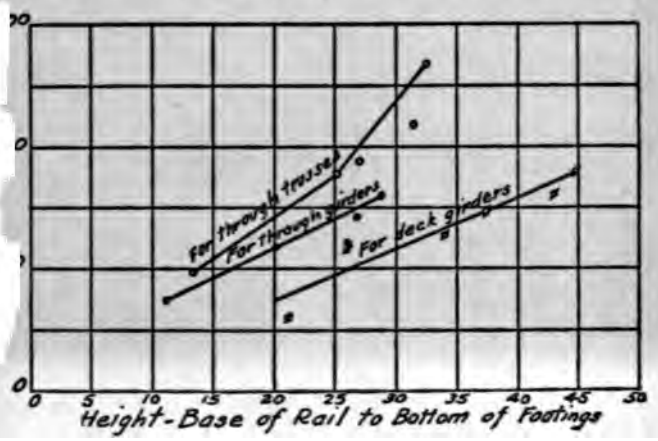


Fig. 75. Volumes of Concrete Piers.

ice and wreckage, however, constitute a formidable menace to the stability of a bridge; and for this reason it is well to have as few piers as possible exposed to the current. Such piers as are exposed should be made massive, well founded to prevent sliding, and shaped to obstruct the current as little as possible and deflect the logs or ice that may be thrown against them. For this reason, piers have their long dimension parallel to the stream, are made as narrow as possible, and are provided with a

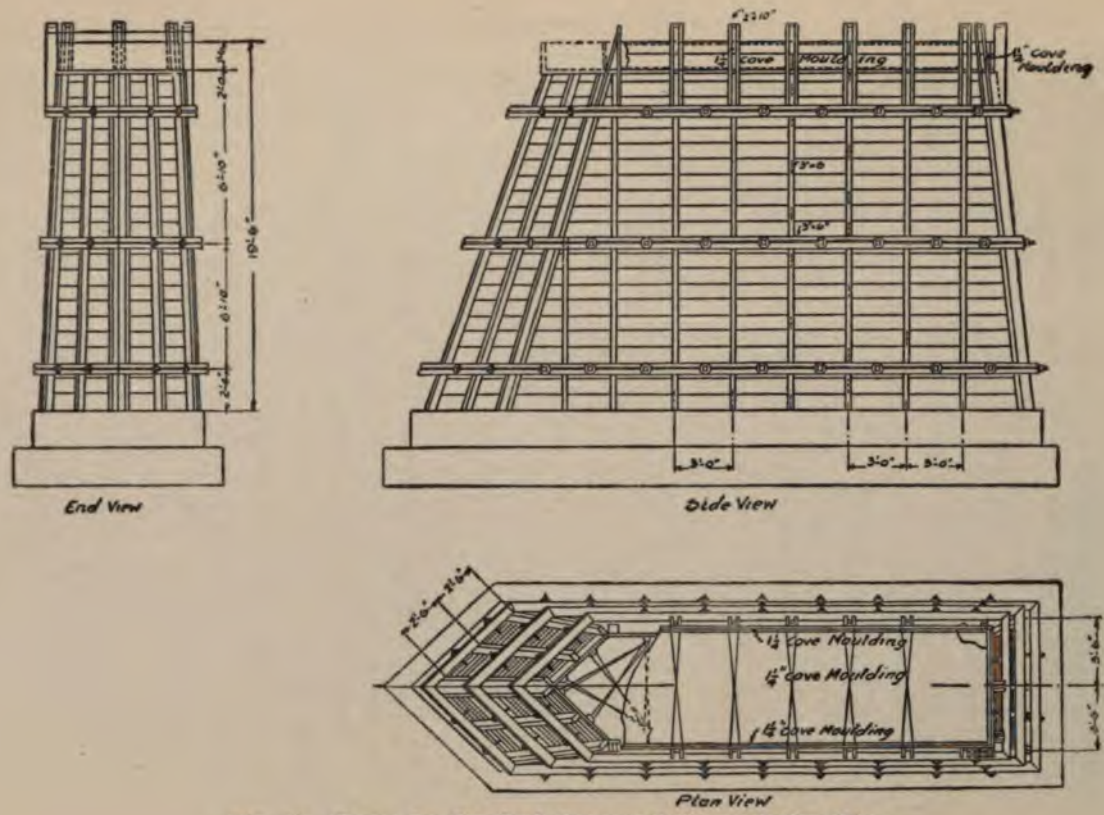


Fig. 76. **Forms for Standard Concrete Railroad Bridge Pier.**

rounded or pointed cut-water or starling at the upstream end. The nose is often reinforced with an old rail, steel bars, or a cast-iron plate.

The final requirement for a well-designed pier—stability against overturning—is usually supplied for ordinary heights if the precautions mentioned above have been taken. In the case of a high pier, however, it is often necessary for the engineer to make additional calculations in view of possible overturning.

Fig. 74 is a standard drawing for a concrete pier showing a top view, side view, and section. On the top view may be seen the position of the bridge shoes or pedestals, and the general outline of the pier including the starling. The "Rules for Design" given on the diagram will assist in filling in some of the blank dimensions; the remainder will depend on the height of the pier, length of the bridge span, nature of the foundation, etc., and must be filled out before the carpenter can lay out his forms.

Fig. 76 is a plan of the form work for a concrete pier.

Bridge piers have been built of piles, timber frames filled with stone, metal cylinders filled with concrete, brick, and stone masonry, but are now generally constructed of concrete, which is an ideal material to answer all the requirements.

For piers of average height, plain concrete is all that is required; but for the center piers of swing-bridges, and for piers of extreme height, it has been found economical in many cases to

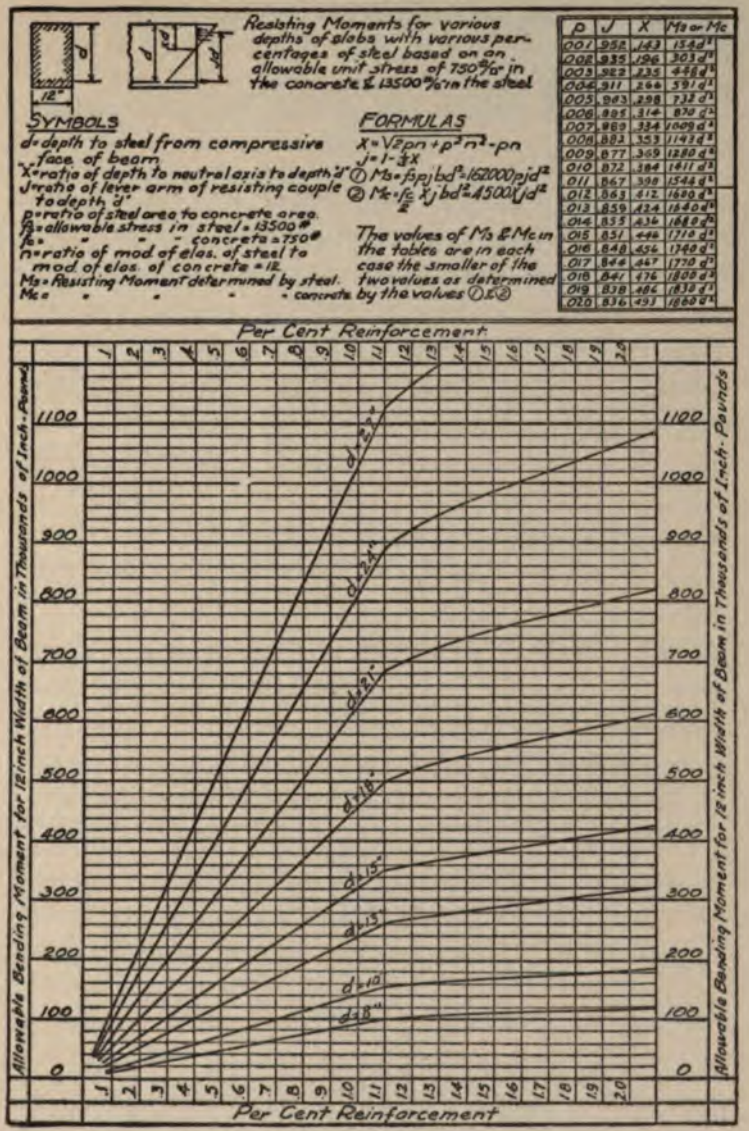

Resisting Moments for various depths of slabs with various percentages of steel based on an allowable unit stress of 750# fo in the concrete & 13500# fs in the steel.
SYMBOLS
d = depth to steel from compressive face of beam
X = ratio of depth to neutral axis to depth 'd'
J = ratio of lever arm of resisting couple to depth 'd'
p = ratio of steel area to concrete area
fs = allowable stress in steel = 13500#
fo = " " " concrete = 750#
n = ratio of mod of elas. of steel to mod of elas. of concrete = 12.
Ms = Resisting Moment determined by steel.
Mc = " " " concrete
FORMULAS
X = √2pn + p²n² - pn
j = 1 - ⅓X
① Ms = fs pjbd² = 162000 pjd²
② Mc = fc/2 Xjbd² = 4500 Xjd²
The values of Ms & Mc in the tables are in each case the smaller of the two values as determined by the values ① & ②
p | J | X | Ms or Mc
.001 .958 .143 154 d²
.002 .935 .196 303 d²
.003 .922 .235 448 d²
.004 .911 .266 591 d²
.005 .903 .298 732 d²
.006 .895 .314 870 d²
.007 .889 .334 1009 d²
.008 .883 .353 1143 d²
.009 .877 .369 1280 d²
.010 .872 .384 1411 d²
.011 .867 .398 1544 d²
.012 .863 .412 1680 d²
.013 .859 .424 1840 d²
.014 .855 .436 1868 d²
.015 .851 .448 1710 d²
.016 .848 .456 1748 d²
.017 .844 .467 1770 d²
.018 .841 .476 1808 d²
.019 .838 .484 1838 d²
.020 .836 .493 1868 d²
Per Cent Reinforcement
Allowable Bending Moment for 12 inch Width of Beam in Thousands of Inch-Pounds
d = 22"
d = 20"
d = 18"
d = 15"
d = 13"
d = 10"
d = 8"
0
100
200
300
400
500
600
700
800
900
1000
1100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Fig. 77. Curves for the Design of Reinforced Concrete Slabs.

are reinforced concrete and to make the piers hollow.

BRIDGE FLOORS OF REINFORCED CONCRETE

The floor of a highway bridge is the pavement or the construction immediately underlying and supporting the pavement: the floor or deck of a railway bridge is the construction supporting the rails, or, in the case of solid floors, supporting the ballast, ties, and rails. In the case of concrete arches filled in between the spandrel walls, the fill takes the place of the decking. In the case of highway bridges with concrete floors, the floor is often provided with a wearing surface and used without any additional paving, thus effecting a considerable economy.

As a typical example of standard specifications for concrete bridge floors, we present those of the Ontario Highways Department:

Specifications for Concrete Bridge Floors

1. **Ferro-Concrete.** Unless otherwise specified, the flooring shall be of concrete reinforced with steel. Wheel-guards shall be of steel channels or of concrete, and such as will prevent the hubs of the wheels striking any part of the bridge. At each end of all spans over fifty feet, steel expansion aprons shall be used with concrete floors.

2. **Material and Labor.** All necessary material, labor, appliances, and implements shall be furnished by the contractor, and shall be such as will secure a satisfactory quality of work.

3. **Steel Reinforcement.** The metal with which the

concrete floor is to be reinforced shall be expanded-metal wire netting, steel bars, or other metal approved by the engineer, and is to be completely surrounded by concrete; and it shall be so placed within the concrete, and shall be of such tensile strength, as to fully provide for the specified loading.

4. **Thickness of Concrete.** Sidewalks shall be four inches in minimum thickness, and shall be made with a slope of ¼ inch to the foot towards the roadway. The minimum thickness of concrete in the roadway shall be four inches at the sides, and five inches at the center.

5. **Down Pipes.** Down pipes, gratings, and other openings or fixtures shall be placed in the walk or roadway wherever required, such openings to be measured continuously as part of the flooring.

6. **Falsework.** Temporary framework or staging shall be erected to support the concrete flooring while in process of construction, this framework to be firm and substantial, of suitable lumber, and, unless perfectly tight, shall be covered with tar paper to prevent the concrete dripping through.

7. **Portland Cement.** All cement employed in the work must be of a favorably known brand of Portland cement, and approved by the engineer. It shall be delivered in barrels or equally tight receptacles, and, after delivery, must be protected from the weather by storing in a tight building or by suitable covering. The packages shall not be laid directly on the ground, but shall be placed on boards raised a few inches from it.

8. **Mixing Concrete.** The concrete shall be composed of gravel and Portland cement, mixed in the proportion of one part by measure of cement to five of fine gravel no stones of which exceed one and one-half inches in diameter. The concrete shall be mixed on a platform placed close to the work, by first spreading evenly a layer of gravel. Upon this shall be spread a proportionate quantity of cement, and the two thoroughly inter-

mixed in a dry state. To this, sufficient clean water shall be slowly added, and the whole again thoroughly mixed and brought to the consistency of a stiff mortar.

9. **Wearing Surface.** The sidewalk and roadway shall have a wearing surface one and one-half inches in depth, of sand and cement mixed in the proportion of one part by measure of cement to two parts of sand, the sand to be clean, sharp, of varying sized grain, and free from loam, earth, or other impurities. The sand and cement shall be first mixed in a dry state, then sufficient water shall be added to properly moisten, and the whole shall again be thoroughly intermixed. This top coating shall be applied to the concrete base before the latter has set, so that a perfect bond between the two will be secured. The surface shall be floated and troweled until smooth and even, and shall be finished with a toothed roller, or as directed by the engineer.

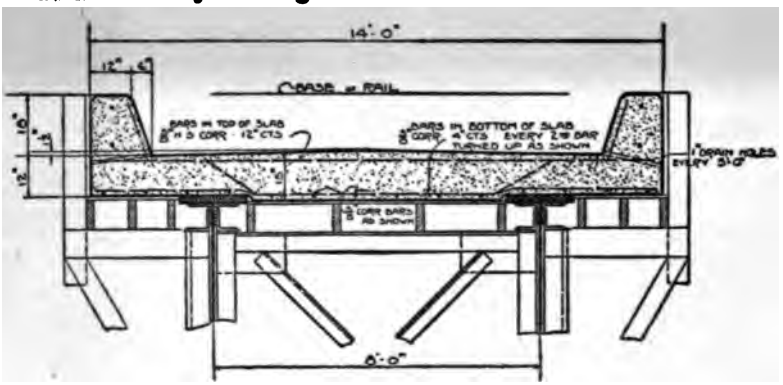


Fig. 78. Solid Concrete Floor for Steel Girder Bridge over Tuscarawas River.

Sugar Creek & Northern Railroad.

10. **Placing Concrete.** While the work is in progress it shall be so arranged that a steady supply of mixed concrete will pass from the mixing-box to the point where it is to be placed. At any time when the work is inter-

Fig. 79. Cross-Section of Reinforced Concrete Ballast-Deck for Steel Girder Bridge.

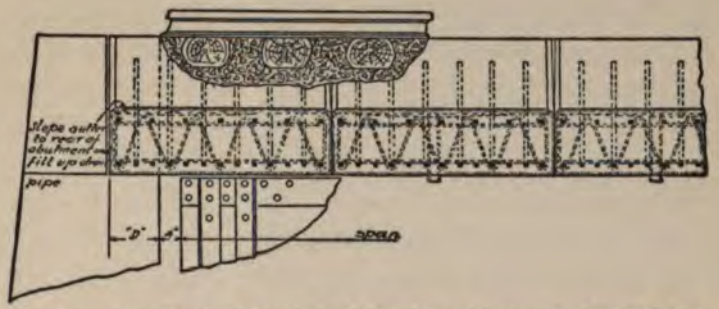


Fig. 80. Longitudinal Section of Reinforced Concrete Ballast-Deck Showing Slabs Built Separately.

rupted before its completion, or at the end of the day, a wet covering shall be placed over the last layer of concrete; and before the work of depositing the concrete is resumed, this surface shall be thoroughly flushed with water to remove any foreign material which may have gathered thereon, and coated with a thin Portland cement grout. No cement shall be laid in wet or freezing weather.

Figs. 78, 79, and 80 are sections of reinforced concrete ballast-decks for plate-girder railroad bridges. Fig. 78 shows the forms for building the floor in place. The floor shown in Figs. 79 and 80 is lifted into place in sections.

SPECIFICATIONS, RULES, AND TABLES FOR REINFORCED CONCRETE BRIDGE CONSTRUCTION

Reinforced concrete construction has been tried and has been proved satisfactory in many thousands of structures, and still it must be admitted that it is in its infancy in the matter of time. For this reason, "good practice" in such construction is not so definitely defined as is "good practice" in the use of older materials in construction. The men most experienced in the use of concrete, however, are pretty well agreed as to the essential requirements for first-class work, and there have been a number of rules and specifications adopted by various societies, commissions, contracting companies, and railroads, which cover the main considerations, and which together furnish a safe guide to all for construction work. In addition to such specifications, there have been numerous articles written by specialists in concrete work, which give an additional source of reliable information for those who wish to accumulate a knowledge of the subject.

The following extracts* are from an article by Mr. W. J. Douglas, Bridge Engineer of the District of Columbia:

"**Some Points in Detail Design.** The first thing that a concrete engineer has to do, after his general lines are

*Reproduced by permission from a copyrighted article in "Engineering News." December 20, 1906, subsequently issued as Reprint No. 12.

A
REINFORCED CONCRETE CULVERT ON LINE OF SOUTHERN RAILWAY.

B
TWENTY-FOOT CULVERT ON LINE OF WABASH RAILWAY.

PLATE 12—CEMENT CONSTRUCTION.

A
REINFORCED CONCRETE CULVERT PIPE.

B
HIGHEST REINFORCED CONCRETE WING ABUTMENT EVER BUILT.

Total height, 61 ft. 6 in. On line of Atlanta, Birmingham & Atlantic Railroad.

PLATE 13—CEMENT CONSTRUCTION.

laid out, is to select the general details of design. . . .

"The elastic theory as applied to concrete arches is very elegant, and every concrete designer should be familiar with it; but in all cases except in that of very flat reinforced arches, the common theory, intelligently applied, is all that is necessary. In the design of the Piney Branch bridge, in Washington, both theories were applied, and the maximum pressures differed under the two analyses by only 5 lbs. per sq. in.

"Don't spend much time worrying about the exact position of the neutral axis of a beam. After you have inspected work under construction for a time, you will be convinced that the way concrete goes into the work does not permit of any hair-splitting application of theory.

"Don't stress your concrete in compression higher than 300 lbs. per sq. in. (mixture 1:2:3) in beams, columns, or arch-work, unless you are going to have first-class inspection; 400 lbs. per sq. in. is high enough when the work is going to receive the best class of inspection. . . .

"Select a design which gives little tension or shear, where possible. Remember that concrete is strong in compression, and weak otherwise. The parabola, catenary, and circle are the best curves for a concrete arch. Arches designed on these lines require little steel reinforcement. Elliptical arches and basket-handle and other flat arches must be heavily reinforced with steel, and should not be used unless the waterway or grade demands it. Very flat arches act more like beams than arches, in spite of the elastic theory.

"**Steel Reinforcement.** It is easier to design concrete work by using steel reinforcement than otherwise. The designer does not have to study his work so carefully in order to make sure that the concrete will not be subjected to tension or shear. When in doubt, reinforce with steel, as it is an axiomatic fact that in all cases it strengthens

the work. Steel is particularly useful for beams, flat arches, and structures whose foundations are poor (in order to allow for deformation), and for reinforcing the foundations.

"Concrete cannot be safely used as a beam without reinforcement, except by using absurd depths. Frequently it will be found, in figuring out the cost of designs, that unreinforced concrete will be cheaper than reinforced concrete on the basis of the same factors of safety, because of the additional expense required in reinforced work for forming steel and the additional cost of placing concrete in narrow forms. . . .

"Bars having a mechanical bond are stronger than plain rods, particularly in work where the inspection is not the best. Bars having a mechanical bond are particularly desirable in vertical and approximately vertical reinforcement, because in these positions they are frequently struck by the laborers and mechanics handling material on the work, and not infrequently by the concrete buckets. When bars are so struck, they lose their adhesion to the abutting concrete, if it is partially set up. This loss of adhesion, in bars of an inch thickness, will extend down as far as 18 inches from the top surface of the concrete. This is one of the many reasons why light reinforcement (small bars in larger number) is better than heavy reinforcement. When the adhesion is broken, you are forced to rely on the mechanical bond. Rods should not be placed closer to corners or other face work than three diameters. It is not uncommon, where the reinforcement is closer, that the concrete on the outside of the rods (particularly where the reinforcement is vertical) will spall off. Small mesh reinforcement must not be used where the aggregate is large, as it is difficult to force the concrete through the mesh so as to completely encase it. It is well in design to keep in mind in a general way the practicability of holding reinforcement in place during the concreting.

Reinforce all thin walls, particularly at their junction with other work—and amply, as they are easily thrown into tension. Do not put in an absurdly small quantity of steel in a large structure, as it has no motive.

"A great deal of money can be saved in the design by using leaner mixtures in foundation and mass work than is common practice. It is not uncommon to see a 1:2:5 mixture which would safely carry a load of 20 tons used in a large foundation where the supporting clay will only carry a couple of tons per sq. ft. Of course, in using lean mixtures, it requires better mixing and better supervision.

"Where first-class foundation soil cannot be economically reached, use reinforcement in the foundations to spread your load over the area, and use a reinforced superstructure in order to lighten the loads on your foundation.

"**Aesthetic Appearance.** The monotonous uniformity of color in concrete work can be varied by using sands or crushed stones of different color, and by using different kinds of tools in dressing the work. This method of varying the color is preferable to using artificial coloring matter, which, as a rule, bleaches out and weakens the cement.

"It is extremely difficult to build long reaches of plain walls quite plumb; and therefore, even assuming that you are going to have first-class inspection on your work, it is well in the design to hide this class of defects by breaking up the plain surface by pilasters having projections from three inches to several feet. Belt courses should be used as often as consistent with appearances for a similar reason.

"Don't use a very ornamental balustrade of concrete. If it is forced upon you, I would suggest turning it over to one of the imitation stone companies who execute this special class of work. Remember that the balustrade or parapet receives constant close inspection by the

public, who are accustomed to fine marble and granite details and are looking for it in concrete work, which is often made to simulate these materials.

"Don't under any circumstances select marble details for concrete work. They are too fine. Select concrete details, and you will get a better-looking piece of work. If you want the best work which can be executed with concrete, trim your structure with stone block, or, if this is too expensive, with concrete blocks, cast separately, and afterwards dressed and set in place. In this way you are sure of your trimming (particularly your corners). Concrete is an excellent filler, not unlike rubble and brick; and in the best designs I think it should be used as a filler. There is no trouble getting good vertical plain faces by spadding or building up the mortar face with the work; but the corners and fine details give a lot of trouble.

"Don't try to imitate stone work. Confess that your structure is of concrete, and design accordingly. Remember that concrete is a new material with new virtues and vices. Forms are permissible with this material that where impossible for the Greeks and Romans, and the olders forms may not be possible in concrete. If the engineering conditions warrant a lintel 75 ft. long, don't make it look like an arch. It is not necessary. Don't dwarf your structure with excessive paneling, which suggests parlor furniture.

"Don't cut up the arch-rings into voussoirs by nailing strips on the lagging to make it appear that the arch is built of ashlar, unless you are going to lay up the work in alternate transverse blocks, in which case it may be desirable. Don't make concrete imitate something that it is not.

"Don't put a lot of gingerbread on a simple structure just because you can get it almost as cheap. Efflorescence does not mar simple details nearly as much as it does ornate ones.

"**Face Work.** Remember, in block work used for trimming mass concrete (that is, work cast on the ground and set in place), that it is not, as a rule, cheaper to use thin veneers with 6-in. and 8-in. beds. Use a bed at least equal to the rise. It does not cost any more money; and when you back it up with concrete, it will stand the pressure of the wet concrete; and if you have sufficient bed, the blocks will be useful in fastening the forms of the mass work. Use hollow spaces or gouge spaces in the back of trimming blocks, to bond the blocks with the mass concrete.

"Remember, in block work, when you cast brackets, dentils, coping, etc., with overhangs, that you can bed these blocks better if they are made of such length that the center of gravity is a good distance from the edge of the masonry below. This costs very little more, and will enable you to bed these overhanging stones without weighting down the back, and will prevent excessive strain on the facing below the bed, which, as a rule, will not stand a concentrated pressure.

"Long, thin concrete blocks to be cast on the ground and set in place should be reinforced with steel so that they may be safely handled.

"On large work permitting the use of air tools, the concrete surfaces may be bush-hammered or crandalled at an actual cost of from 1 ct. to 3 cts. per sq. ft. Tooling a structure gives it a better appearance, removes form marks, lipping, and efflorescence. Efflorescence may be permanently removed in this way, provided, before its execution, the drainage of water which has been carrying the efflorescence to the face of the wall has been cut off.

"Large masses of concrete having cross-sections of over say 200 sq. ft. will frequently hair-crack when the concrete sets up. In using the word 'hair-crack' in this connection, I mean long, thin hair lines running vertically up the face of the mass work, somtimes at inter-

vals of 10 and 20 ft. These hair lines are apparently independent of temperature, and are due to the concrete in the face of the mass work setting up before the interior. These hair lines are not seriously detrimental to the structure nor are they noticed by laymen. However, on a 'show job,' you may overcome this trouble by using a light reinforcing of expanded metal, wire mesh, or light rods, about 4 ins. from the face.

"**Waterproofing and Expansion.** On large work, make your stepping at the back of retaining walls in rises of about 4 ft.—smaller heights are unnecessary in large work, and entail additional cost. Don't build the backs of concrete retaining walls on a batter, as they are not as stable as stepped walls containing the same amount of masonry. Slope the treads of all steps at the back of retaining walls at least one inch to the foot, if you want a dry-showing face. This precaution is worth any amount of waterproofing. If you get pockets at the back of retaining walls which will hold water, you can't expect the waterproofing man to prevent seepage.

"Don't apply paper to vertical walls, as it frequently bulges, making pockets which hold water so that practically the water is forced through the wall. All that the back of a retaining wall properly built needs is a couple of coats of coal tar, which must be applied when the surface of the concrete adjacent to it is dry—not superficially dry, but when the concrete is thoroughly set and the wall is dry for several inches in from the surface. Then place a light stone drain at the back of the wall as the back-filling is made. Then back up your weep-holes with half a yard or more of broken stone; a handful of stone soon gets stopped up by silt.

"It is a common error in subway construction to take great care in waterproofing the roof, with often satisfactory results, but to take no precautions to carry this water over the expansion joint at the abutments. This

results in the water running off the roof and down the face of the abutments.

"In applying waterproofing on approximately horizontal surfaces, apply the waterproofing in consecutive layers, after the method of shingling (the shingling should be done in the direction of the flow), and iron smooth upon the completion of these applications.

"Provide for expansion in retaining walls by using construction joints about every 50 ft. Provide for uncertain foundations in a similar manner. Provide expansion and construction joints over arches. Use expansion joints at the abutments over piers in such work, and construction joints on the haunches.

"If it is economical to use an arcade of spandrel arches resting on your main arches, run the axes of these spandrel arches longitudinally rather than transversely. Of course, this cannot be done if a vista is desired through the spandrel, or if, on account of freshet or other local causes, open spandrels are required. Longitudinal spandrel arches are easier to construct, and simplify the expansion.

"If concrete piers are subjected to the impact of heavy floes of ice, they should be protected by a nosing of stone or iron.

"Use fillets on all corners, excepting where the corners are built of coign blocks which have been cast separately on the ground and tooled before setting. It is practically impossible to get and maintain a fine arris by moulding concrete in place, and therefore I suggest fillets. Concrete arrises are difficult to cast and maintain; and therefore, on dressed work, I would file the edges to a ⅜-in. radius.

"Gravel is practically as good as broken stone for aggregate, but concrete made of gravel cannot be tooled. Small deformations in the mould can therefore not be corrected in spaded gravel work.

"When concrete is to be used as a beam or column,

thin wall, or arch, specify the best materials obtainable in your community. Concrete for this class of work must be carefully mixed and placed, to produce a homogeneous mixture.

"On work requiring various grades of concrete, it is more than necessary, in the specifications, to vary the portions of cement, sand, and stone. The quality of the materials might profitably be different, and the method of mixing and placing concrete should be more careful for such work as beams than is necessary in mass work.

"Many engineers seem to think that concrete is concrete, and that the same care should be taken in the proportions, mixing, and placing in one case as in another. As a matter of fact, you can be a great deal more liberal with a contractor on heavy foundation work than in building a reinforced beam, and the contractor should be given the benefit of this fact.

"In designing, assume that you are going to have unskilled mechanics to do your work. It is almost impossible to get a good concrete worker unless you educate him, and this is up to the engineer, his foreman, or inspector. This is not the case on other classes of construction, where the details of construction can frequently be left to experienced mechanics.

"Remember, in designing and also in construction work, that concrete in setting shrinks and that there will always be a very small crack existing between abutting sections of concrete work executed at different times. Concrete which sets up under a head shrinks less. Concrete rich in cement shrinks more. Concrete made with coarse sand shrinks less than that made with fine sand.

"Detail your bidding sheets so that the bidders can tell exactly the amount and kind of reinforcement required. Ask for prices on additional concrete of its several classes, and for additional reinforcement of its

several classes. You will find as the work progresses that there will be many places where extra concrete and extra reinforcement are desirable.

"**Specifications.** Don't finally pass upon specifications until your drawings have been finished and approved. Be careful to specify material which can be procured, and preferably what is commonly in the market. This will save your client money, and yourself considerable bother.

"Don't specify methods of procedure on work in which you are not experienced. You can get experienced bidders competent to lay out their own method of procedure; and if not, a closer study of the subject than is frequently possible in the writing of specifications will enable you later to determine upon better methods than can be decided upon off-hand.

"Remember that no specifications at all is better than bad ones. Just say that the work shall be first-class according to the common practice in your own vicinity (or some other, if it is better), which is about all that is intended by most specifications. If you take upon yourself the authority to specify in detail just exactly how a contractor is to proceed with the work, do not then specify that the contractor shall be responsible for the work. If you want the contractor to be responsible for the work, write a general specification describing the class and character of work desired, leaving the details to the successful bidder to work out.

"Don't put things in the specifications which you do not mean to enforce, as it costs your client money and frequently keeps away desirable bidders. Sometimes engineers put in club clauses for the purpose of keeping contractors in line. This is, of course, unnecessary.

"Don't copy old specifications blindly. You can seldom use a standard specification for concrete without adapting it to local conditions. Don't preserve dead letters in your specification. Here are a few clauses

which I incorporated in my own specifications in 1898, but which have been omitted in more recent ones; I think they will still be found in use by a great many engineers in their specifications, but not in the actual construction:

"'Concrete shall not be passed down to its place through a chute or thrown or dumped from a height, but must be carefully lowered in a vessel, and so carefully placed as to contain the constituents evenly incorporated as mixed and entirely free from foreign matter of any kind.

"'Each batch of concrete shall be spread in place in horizontal layers not exceeding 6 in. in thickness, and shall be at once thoroughly compacted by ramming with rammers weighing about 25 lbs. each. Sufficient water must be used in making the concrete to enable the proper results to be obtained, but not enough to cause the concrete to quake under the rammer.'

"In regard to the second paragraph quoted, I wish to state that on a great deal of work where a reasonably rich concrete is in use it is neither impracticable, in my judgment, nor undesirable, to bring the concrete up in 2-ft. layers if wet concrete is used. This, of course, is impossible when you get above ground—that is, on finished work—as such a course would be too deep for the spaded face work. There is a tendency, I believe, in the profession, to increase the layers on mass work; and I think possibly it results in getting better concrete. These large layers, of course, were impossible under the old system of using dry concrete. As to the rammer referred to, I might say that most work at present is spaded, the rammers only being used occasionally when a dry batch is brought on the work, more often by accident than design.

"The use of fine sand for concrete is deprecated where the concrete will be highly stressed.

"Good crushed rock makes the very best sand; but

in passing upon crushed stone in lieu of sand, look out for rotten dust. Rotten rock going through the crusher is, as a rule, crushed to dust.

"Do not specify ornate details with spaded work, nor fine arrises. If these are desired, use a mortar face, or, what is better, use broken stone throughout from ¾-in. or ½-in. down, depending upon the size of details desired. Tests indicate that a concrete made of the small aggregate is practically as strong as concrete of a large aggregate for the same percentage of cement.

"Plastering the surfaces of concrete before the next day's work is begun is unnecessary. Concrete should be kept wet as long as practicable, provided efflorescence is not more of a factor than 8 or 10 per cent additional strength.

"Concrete can be laid in cold weather in large masses in water and below the surface of the ground. One of the best ways to protect it below ground, is to permit the water to rise up over night, and then pump it out the following morning. The laitance and silt which accumulate under such procedure, of course, should be carefully cleaned off.

"**Forms.** The engineer should carefully study the forming of the work to be done, prior to the award of contract, and should specify in a general way the class of work which will be required of the contractor.

"A great deal of work is seriously marred by the lack of rigidity in the forms. Designers use the same size wales and studding, whether or not the work is to be carried up 2 ft. or 10 ft. The height of a day's work should be always considered in the design of form, and the maximum height of a day's work used. Extreme care should be taken to reinforce corners of the framing. In designing forms for my own work I assume that concrete is a liquid of half its own weight; that is, 75 lbs. per cu. ft. This rule has resulted very satisfactorily.

"Forms should be designed so that they can be used

in duplicate. It requires a great deal of study frequently, to design the forms so that they can be so used; but it means a great deal of money in the contractor's pocket.

"Bevel all small projections on forms for rustic joints, etc., so that these forms can be taken down without tearing off the edges of finished work. Bevel at least $\frac{1}{16}$-in. to the foot. The designer of forms should always consider the practicability of the economical removal of forms without injury to the concrete.

"Forms built up in section lengths should have these section lengths not longer than 6 or 8 ft. for convenience in handling and removal without injury to the complete work. For beams, camber the bottom of the forms slightly, so that any sag in the form will not give the appearance of sag to the beam.

"The contractor should be required to stop up all cracks in the forms with mortar or putty, so that the mortar will not give way. Tongued-and-grooved dressed flooring or similar lagging should be used on all face work, even if this work is to be dressed afterwards, because, if these forms are not practically water-tight, the mortar facing will get away, necessitating unsightly patches on the completed work.

"There is no practical difference in the appearance or strength of concrete, whether wood, sand, galvanized iron, cast iron, or plaster paris is used in the face-work forms.

"**Arch Centers.** It is thought that better results can be obtained, and also a lower price secured for the work, if the engineer designs the centering before bids are asked. It is certain that it gives the average contractor an opportunity to make a more intelligent bid. If the engineer is not experienced in this class of work, I would suggest that he leave the design entirely in the hands of the contractor, not attempting to cover the description of the center except in a very general way. I would

suggest the following specifications for an inexperienced engineer:

"'Complete drawings of the centers with a complete description of the various materials to be used shall be submitted by the contractor to the engineer.

"'The center shall be built for the full width of the bridge, and the crowns of the centers shall be raised above the intended height of the finished arches to allow for settling when the centers are being loaded and when struck. The centers shall be provided with striking wedges or sand boxes so that the lowering of the center may be effected slowly. The lagging for the center may be in two or more thicknesses if the contractor so desires; but the top layer shall be tongued-and-grooved lumber, and the lower layers shall be dressed to match the top surface when in place. Lagging shall have a deflection under the full load of the arch of not more than ⅛-in. The settlement of the center under its full load shall not be greater than ¾-in. for each 30 ft. in vertical height.'

"Under such specifications the centering should not be paid for directly, but payment for same should be included in the price of the arch concrete in place. On large work I would suggest that the contractor be required to furnish ample fire protection. On one piece of work under my supervision, requiring nearly 2,000,000 ft. of lumber, the contractor installed a 4-in. water pipe, with hose connection for each arch.

"**Engineering Supervision.** On small work it is necessary frequently to get along with a single inspector, whose duty it is to see that the forms are erected on the lines given by the engineer; that these forms are stiff; that the materials and workmanship are in accordance with the specifications and approved plans; and that the reinforcement is properly placed. In addition to this, he looks after the removal of the forms, to see that the concrete work is not injured in careless removal, and

that all corners are properly protected by wooden strips upon the removal of the forms. To this is added, as a rule, the clerical work of keeping track of the extra work and also the general cost of the work in its several details.

"If you have to break in a green man for this work, I would suggest selecting a carpenter. It is more difficult to get a good man to look after the forming than any other part of the work, excepting that of getting a good face, and if you have not a man experienced on face work you had better camp out on the job when it comes to this part of the work. Contractors will help themselves a good deal by getting experienced foremen and mechanics for face work. Wood butchers and cheap labor will not pay a contractor who is trying to get a high grade of finished work. Contractors should bear in mind that finished concrete work requires skilled labor, just such labor as is required for first-class stone and brick work.

"On any work, say, over $20,000, to be executed in a working year, I would suggest placing an additional low-grade inspector on the mixer. It occasionally occurs that the laborer pouring in the cement, through carelessness, does not put in the right amounts, and I recall two cases on my own work when the cement was entirely omitted. Of course, on work executed in daylight, this omission would probably be detected, owing to the variation in its general appearance and color; but on night work it might get into the work and afterwards cause serious trouble. It is also quite common for a laborer to throw out one-third or more of hard, lumpy cement without compensating for it. This does not make so much difference in mass work; but in thin work it is, of course, vital.

"It has been my practice to prohibit finished concrete work at night, although, if the contractor would provide a sufficient number of arc lights, there is no reason why

the finished work cannot be so executed. Another reason for having an additional inspector on the mixer is that, as a rule, material is more or less superficially inspected by the engineer or inspector by going over the top of a car or barge and digging up a few pockets here and there. Both sand and gravel, however, frequently contain layers of mud near the bottom, which the additional inspector on the mixer would be able to see and condemn.

"Lines and grades must be given more frequently on finished concrete work than on other classes of masonry, as it is difficult to correct small errors without unsightly results. It may be said in general also that the cost of inspection under existing conditions is higher, in order to get a first-class finished concrete job, than it would be for the same amount of brick or stone. It is thought that from 1½ to 2½ per cent of the total cost of the work is a proper charge for inspection on first-class concrete work.

"Records of the actual cost of all work should be kept, where possible, in order to determine upon the proper price for the extra work. The various inspectors and foremen under the direction of the assistant engineer should agree each day as to the actual cost of the extra work. Assistant engineers should go over the extra work at least twice a month with the contractor's superintendent, so that the detailed cost may be properly adjudicated while the several items are fresh in the minds of the entire force. Very complex bookkeeping details, of course, generally result in their untimely death before the completion of the work; or, what is worse, in the loss of efficiency in the engineering and inspection forces. Clerical work is a serious problem to most first-class inspectors, and therefore their reports should be simplified for them as much as possible by the use of printed forms.

"**Contractor's Plant and Construction Work.** Don't hurry your contractor until he has had a reasonable time

to get his plant together. Good work cannot be executed with a poor plant at what are ordinarily reasonable prices. It is suggested to the contractor to bear in mind that stone crushers and concrete mixers seldom have enough power behind them to produce their rated capacity. Concrete mixers should be selected which have been in successful use. To get concrete to and from the mixer is more difficult than to mix the concrete. Mixing by hand in small quantities and at isolated points is frequently cheaper than machine. A first-class concrete plant will cost from 5 to 10 per cent of the total cost of the work. Besides handling concrete, the plant, as a rule, has to do the following work (difficult foundation not considered): Excavate; sheet-pile; mix and transport mortar; mix and transport concrete; handle lumber for falsework and forms (including demolition); handle steel, coal, broken rock; and back-fill. Several of these items should be carried on at one time to execute the work economically, which gives preference, as a rule, to derricks rather than cableways.

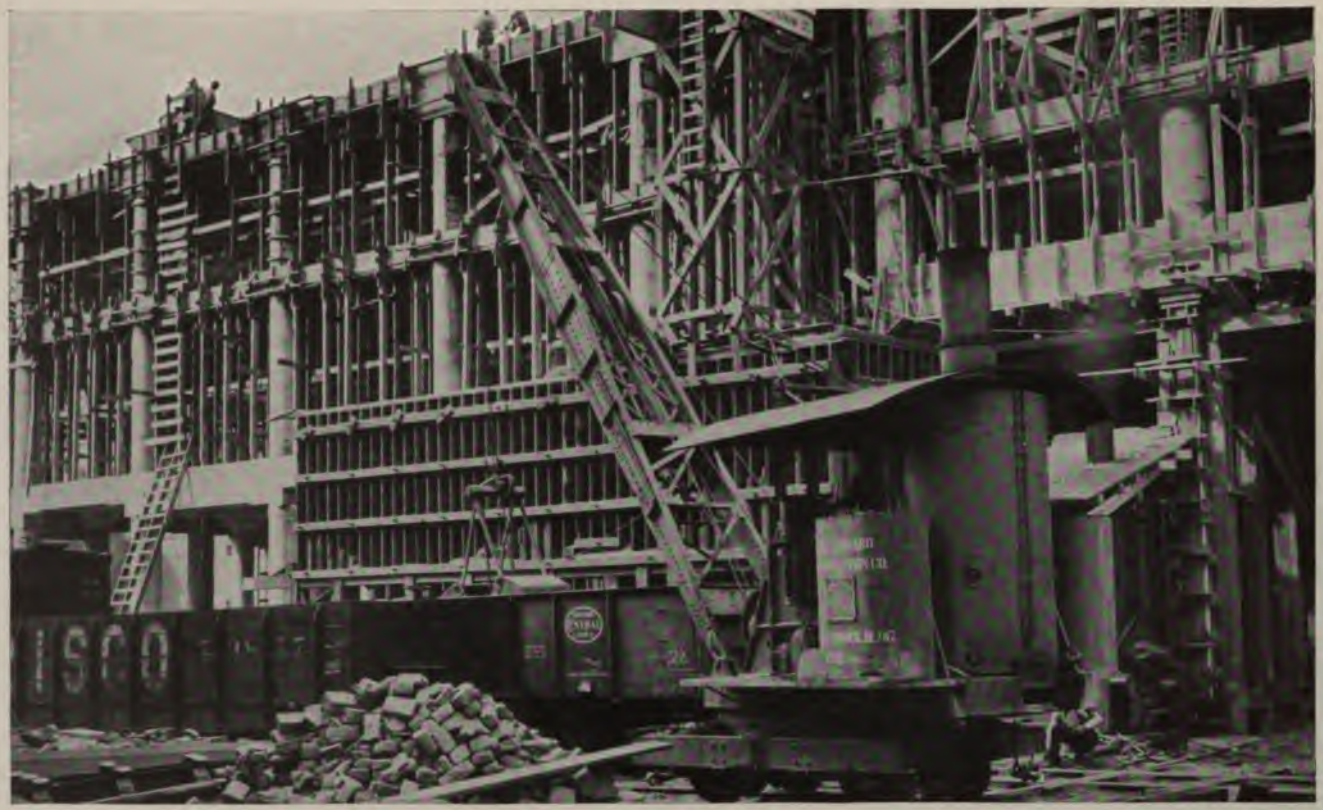
"**Mixer.** In selecting a mixer, give preference to a batch mixer which has been in successful operation a number of years. In this connection, however, I wish to say that the best tests I have ever had were from a continuous mixer of the asphalt type; but I think it requires more careful inspection to use this machine than it does the batch mixer. In such work as arch work, where a large monolithic day's work is necessary, be careful to select a mixer which does not easily get out of gear.

"If the contractor is to use a machine which is not known to you, or if you are not satisfied with the concrete which it is turning out, I would suggest the following test. I have found it a very valuable one on my work. In one case I found that a mixer whose product did not size up well to the eye was only giving me 60 per cent strength of what might be regarded as a first-class concrete. An experienced man would probably be

A
A 24-FOOT COUNTERFORT RETAINING WALL IN LACKAWANNA TRACK ELEVATION, BUFFALO, N. Y.

B
METHOD OF HOLDING REINFORCEMENT IN PLACE.

PLATE 14—CEMENT CONSTRUCTION.



BUILDING FOR JOHN DEERE PLOW COMPANY, AT OMAHA, NEBRASKA, IN COURSE OF ERECTION.

PLATE 15.—CEMENT CONSTRUCTION.

able to detect the fact that the results were bad, but even experience can well be supplemented by practical test.

"Take the concrete as it comes from the mixer, and from this concrete take several handfuls of mortar from different parts of the pile until you have a shovelful. Then, being careful not to mix this mortar at all, make six briquettes from it. Then take several shovelfuls of concrete from the different parts of the pile of concrete, until you have enough for six cubes. These cubes should be at least four times as large as the largest dimension of the broken stone used in the concrete, and preferably they should be 12-in. cubes, if there is an accessible machine large enough to crush such a cube. In making up the cubes, be careful not to mix the concrete. After you have made the briquettes and cubes just described, have the remaining concrete turned over by hand four times. Then repeat the sampling, making six briquettes and six cubes. Then store the two sets of briquettes and the two sets of cubes under exactly the same conditions, and break them in from seven to thirty days. The latter is preferred if you can take the time. The tests of the second set of the briquettes and cubes should not show an increase in strength of 10 per cent over the first set. However, if over 10 per cent and less than 15 per cent, I would suggest a second test, the results of which should be final.

"Lean mixtures require more mixing than rich ones. Dry mixtures require more mixing than wet ones.

"In feeding a continuous mixer by shovel, see that all of the material is fed at the loading end. It is not uncommon to see at least one of the shovel men feeding his material at the dumping end. Permit the retempering of concrete where the set is not so hard as to require a pick, provided the practice is not habitual. Do not split hairs on the mathematical proportions of the several materials which make up your concrete. This frequently

squabbling with the contractor without ing from it. Don't make the contractor pick out every piece of string, twig, or leaf which you happen to see going through the mixer.

"Gravel.—Gravel. Do not accept slimy gravel (when wet), nor gravel containing many mud balls, or a large percentage of gravel cemented with mud.

"Broken Stone. Do not accept stone with a large percentage of tailings, nor stone with more than 15 per cent of stone dust, nor more than 1 per cent of weathered rock, nor stone a noticeable percentage of which goes to pieces under the hammer. My objection to a large percentage of stone dust is that, as a rule, rock which, when crushed, gives a large percentage of dust generally contains considerable soft rock, which is ground to dust in its passage through the crusher. In using run-of-crusher material, study crusher conditions so as to obtain a reasonably uniform product.

"Cement. The cement house should be sufficiently large to store about 30 per cent of the annual work; or, what is practically the same thing, it should be large enough for two months' storage. The house should be of such size that the cement can be piled and kept in separate car lots.

"For mortar face work, samples should be taken from each barrel—for general work, on the basis of one sample to ten barrels; all bags sampled should be properly marked, so that they may be resampled if necessary. Cement should not be stored in a damp place. Hard lumps should be thrown out and replaced by good cement.

"Sand. Sand should not contain more than 10 per cent of silt, except where actual tests indicate that the sand proposed is as good as the average sand generally used in the locality where the work is being executed. In this connection I have to say that I recall a case of my own work where sand containing 16 per cent of silt gave a very much better result than a sand containing

no silt and which had been originally intended for filtration purposes. On waterproofing work, as a rule, a large percentage of silt is desirable up to, say, about 15 per cent, but facing work should not, as a rule, contain over 5 per cent, as the greater amount of silt in the concrete, the greater amount of slime there will be carried to the face work.

"In placing concrete upon a sand foundation containing a sand without any silt in it, I noticed that the concrete was being robbed of its water. We were putting in soupy concrete. Fifteen minutes after it was placed, it was almost dry. Besides this, I noticed that where a layer was allowed to stand a few minutes without any abutting concrete, the water of the concrete had washed a part of the sand out of the concrete, and also a part of the cement. There was a ring of sand about 5 in. from the end of the layer, and the cement was extended somewhat beyond that. The sand used was a fine sand in this case. As a result of this observation, I accepted a coarse sand containing about 12 per cent of silt, which held its water satisfactorily.

"**Sand Test.** On large work I have recently used the following method of testing sand, which has been quite satisfactory: Wash a considerable quantity of sand; separate the silt from it; then make up a special sample from the sand and silt that you have separated, so that this latter sample will contain the maximum silt allowed under the specifications. (If the contractor is furnishing sands from more than one locality, it will be necessary for you to make the test herein described from samples of each of the localities, as will readily be seen from the nature of the test.) Take the specially prepared sample just described, and thoroughly mix the silt with the sand until the distribution is uniform. Then take a small portion of the proposed sample, about three thimblefuls (on my own work I have given the inspector an ordinary test tube, with a mark on the test tube

indicating the height of the final sample of sand required). Take this small sample of the prepared sand, drop it into a graduated beaker of clear water about 30 in. high (on my own work I have used the local hydrant water, which is filtered and reasonably clear at all times of the year); shake well until the sample has been thoroughly washed. Then take a domestic pin on the end of a wire or small stick, and insert it in the top of the beaker, lowering it into the beaker until the pin is no longer visible from the top, and then read the position of the pin on the graduation at the side of the beaker. Make half a dozen similar tests, using the prepared sand, and the average of these samples will be the correct gauge for sand which does not contain over the stipulated amount of silt.

"Of course, it is not necessary to sample every car load or barge of sand that comes in, as the bulk of it can be determined by superficial observation. If you are in doubt, however, take a number of shovelfuls of sand from various parts of the car or barge, mix thoroughly, and take out the necessary amount of sand for test. Drop same into the beaker, shake, lower the pin, and read the gauge. If the pin is then lower than the gauge, the sand has less silt than the maximum; if it is higher, it has more silt.

"This is a very cumbersome thing to explain, but it is more practical than it sounds. When I first suggested it to the men engaged on the work, it was thought to be too hair-splitting to be of any practical value; but after it was actually put into use, it was entirely satisfactory and enabled the men to make immediate tests of the sand, instead of waiting half a day, which would be necessary under the common method; and it permitted a great many more samples to be taken. If you use it, it will take about an hour to get your first sample prepared and your gauge determined, after which two or

three minutes will enable you to make the test. (This system I first saw used by Mr. Allen Hazen.)

"Condemn sand for a noticeable quantity of mud balls, regardless of test. In this connection an inspector should use some judgment as to the nature of the mud ball. Sometimes these mud balls are almost solid chunks of mud, and at other times they contain nearly all fine quartz, with a very little mud.

"An engineer should make briquettes of the different classes of sand on his work, in order that he will be certain whether or not he is warranted in accepting sand with a slight excess of silt rather than a finer or poorly graded sand which comes well within the specifications as to silt.

"**Construction Work—Forms.** See that the forms are built to the lines and according to the approved plans. See that the lumber is sound, and all wale joints are well spliced; that lumber, where toe-nailed, is efficiently nailed; that all forms are plumb; that all form rods have washers under their heads and nuts; that they are taut when concreting is begun, and that they remain so during the progress of the work.

"Forms are designed for a certain number of vertical feet rise for a day's concrete work. Find out how many vertical feet. If for any reason the concrete is changed from a dry concrete to a wet one, consider the number of feet rise permissible under the changed conditions. In this connection I wish to say that the keeping of forms plumb is the most difficult thing which devolves upon the engineer, the contractor, and their assistants. The building of plumb vertical walls can be obtained only when everybody on the work looks out for them. I have seen some very excellent concrete work done in different parts of the country where nearly all of the concrete walls were as much as 2 or 3 in. out of plumb.

"Inspectors should report to the assistant engineer any undue cutting of washers into the wood; also all

form rods which have broken under the strain of the concrete. See that tongued-and-grooved dressed lumber is used where required.

"Use sized studs for all finished work. See that the forms are held tightly when beginning a day's work. If they are not, the load of the fresh concrete will push out the forms, causing not only lipping, but the mortar above will flow into the crack thus formed between the lagging and the old concrete, which will make a hole in the face work. See that heavy reinforcement is placed within the forms before the form tie-rods are placed, as these tie-rods frequently interfere with the placing of heavy reinforcement. Forms for finished work must be held together by tie-rods with coupling placed at least 3 in. from the finished face to permit of removal of all iron within 3 in. of the finished face. This is done in order to prevent rust stains. Forms may be held by wire on unfinished work.

"Have the contractor so lay out his work that he will reduce the walking over and the working-on on all settling concrete to a minimum. Allow the contractor ⅜-in. departure from established lines on finished work, and 2-in. on unfinished work. (The latter may be increased indefinitely, depending on the size and nature of the work, but as a general rule the forms should be within 2 in.)

"**Block Work.** Soupy concrete—that is, concrete which contains about one more bucket of water than the concrete specified for mass work—should be used on block work. This will enable the moulders to bring out the details and arrises more strongly.

"Facing stone dust or grit and facing sand should all have all coarser material removed by screening; ½-in. mesh is small enough for large blocks and large details; use ⅜-in. mesh for fine work. Be careful, in passing upon the stone dust, that it does not contain a large percentage of rotten rock. All mud balls must be re-

moved for facing work. The backs of all blocks should have recess places in the back, covering practically one-fifth of the area in the back, for the purpose of bonding with the mass. These recesses may be best obtained by placing wooden blocks, say, 6x6-in. or 8x8-in., in the concrete when first deposited, and removing same before final set.

"Cast all blocks with most important face down. All other showing faces should be cast vertical, or as near vertical as practicable. The back of the block—that is, that portion of the block which will not show in the structure—should always be moulded up, because the laitance or slime always rises to the surface, giving it not only a bad color, but a weak surface, and one which is certain to hair-crack. All blocks should be moulded in forms which are level—that is, which rest on a level platform—and great care should be taken by the inspector to see that the forms are stiff and do not bulge or distort under the concrete. If this is not done, the contractor will find it necessary to do a great amount of cutting, which in many cases will result in going through the mortar facing in order to get the block out of wind. All blocks should be left on their bottoms from two days to two weeks, depending on the size of the block, the nature of the cement, and the condition of the weather. If not, they will be liable to break in handling.

"Concrete should not be dressed (tooled) until 30 days old, under normal conditions—preferably not under 60 days. Before casting the several classes of block, it should be agreed between the contractor and the inspector as to the method of handling the block, so that there will be no dog or lewis holes in the showing faces. I found on my own work that this question is overlooked frequently in the design and moulding of the blocks.

"Lewis holes should be cast in the blocks where practicable. Bear in mind that lewis holes must be so made

as not to bring excessive pressure on the concrete, particularly near the mortar facing or near the arrises of the block. Remember that you are not handling granite. Be careful not to handle large blocks with lewises or dogs when they are green, as you will meet with disaster. The contractor must provide wood blocks and rag cushions in turning over the blocks; otherwise the arrises will be broken.

"One-quarter to ⅜-in. should be allowed beyond all neat lines for dressing. All arrises should be chiseled. Better work can be got by using hand hammers than machine ones; and concrete details subject to close inspection by the public should be hammered by hand. All arrises excepting those of abutting joints should be rounded to approximately a ⅜-in. radius. If this is not done, the public will eventually knock off the fine arrises. Use metal templets for cutting important details.

"Modify all blocks which you are unable to cast satisfactorily. Inspectors should report all blocks which in their judgment need additional reinforcement. Check all forms just before moulding, and keep a record of the blocks cast, and see that they are being cast in the order required on the work. Paint the date of casting on each block, and keep careful record of them.

"Cover all blocks in warm weather with rags, bags, etc., keeping same covered and damp for ten days. Do not cast blocks in freezing weather (particularly thin ones) without taking extraordinary precautions to protect the concrete from the cold.

"**Concrete Mass Work.** The inspector in charge of the mass work shall, before the mass concrete work is begun, receive from the form inspector an approval of the forms or shall personally examine them to see that they conform to line and grade, and that they are in accordance with the approved plan. He shall note, before beginning this work, that all laitance, mud, chips, and dirt have been cleaned off the surface of the concrete,

and that the forms (for finished work) are also cleaned of all dirt and cement. A very unsightly face is often produced by leaving the mortar on the forms, which has resulted by the throwing of concrete into the forms in the previous day's work. He shall be governed by inspections from the assistant engineer as to the height which the contractor may be permitted to carry up a day's work.

"Concrete shall be placed in 9-in. courses on finished work. With the consent of the assistant engineer, concrete may be placed in courses of 2 ft. on heavy mass unfinished work.

"On finished work each day's work shall be brought accurately to horizontal and vertical surfaces. If this is not done, the lipping which nearly always shows will be ragged and therefore unsightly. The positions of bulkheads and the height to which the finished work shall be carried shall be so selected as to assure a neat bonding appearance in the finished work. The contractor should so arrange his work that the concrete may be brought up at least 2 ft. in a day's work.

"Don't finish the day's work too close to an ornamental detail. You will find, if you do, that you have lipping where you can least afford it.

"In waterproofing flat concrete surfaces with consecutive layers of tar or other similar material, apply the layers so that they will be shingled with the direction of the flow of water, and iron well. Don't apply waterproofing material rich in water—that is, which is full of water bubbles.

"On extra work, the contractor is entitled to pay for moving his plant or machinery to and from another part of the work, provided the extra job is on a part of the work previously declared finished by the engineer.

"Breaking into the contractor's gangs for men on odd extra jobs should not be resorted to unless absolutely necessary. However, the contractor must, as a

general rule, have enough elasticity in his force and plant to handle the current extra work with the same degree of facility and economy as the contract work proper. Extra work must not be continually sacrificed to the contract work proper.

"In paying for the use of machines under extra work, the engineer will agree with the contractor on the price per hour complete in operation, or, where extra work is continuous, on the basis of the price per day. Inspectors should compare the time of men and plant on all extra work with the foremen every night, and a similar comparison should be made by the superintendent and assistant engineer twice a month.

"Forms on finished work should not be removed in less time than from 3 to 14 days, depending on the setting of the cement, the condition of the weather, and the height of a day's work. Forms on unfinished work should not be removed in less than from 12 to 72 hours, depending on the foregoing.

"On each new part of the finished work, the forms should be removed as soon as practicable, so that it may be assured that the method of placing the facing is a good one; if not, there will be a chance to improve upon similar sections of work.

"All layers of concrete should be horizontal, except near the skewbacks of heavy arches, where they should be inclined as nearly to right angles to the thrust of the arch as may be consistent with a compact concrete. A drier concrete than is generally used in mass work may properly be used here. The contractor should be required to set wooden blocks from 6 in. x 6 in. x 2 ft. to 8 in. x 8 in. x 4 ft. in the concrete, taking up approximately 10 per cent of the area in the finish of each day's work. These doweling blocks should be removed the following day. This is done for bonding purposes, and great care should be taken to see that this rule is carried out at all abutting sections of transverse arch blocks.

"All mortar for face work should be made by hand or a regular mortar mixer.

"The contractor must not continually change the facing hands who are skilled in this class of work. The uniformity of the appearance of concrete work is desirable, and is dependent largely upon this class of labor.

"Transverse and longitudinal arch blocks must be cast continuously, and the contractor must not start such work unless provided with sufficient plant and material to insure the finish of such a section continuously.

"The concrete should be of such consistency in general that a man in walking about in it will sink ankle deep. This may be somewhat cut down in cold weather.

"Note the color of the concrete; and if it varies considerably, examine for cement. Find out whether the variation is due to the color of the sand or stone or variation in the cement. Occasionally a batch may get into the work with little or no cement in it, if the color is not kept in mind.

"Keep your work always neat as to the grade of the concrete. If the work is not handled systematically, you cannot get first-class work, nor will it be economical to the contractor.

"Keep your face work always high, so that any of the concrete water which may accumulate will not go to the face work, for if it does it will weaken your face work and carry to it a lot of slime or laitance; silty sand is not good for face work.

"If your concrete is too wet, don't bail out the water, as it is full of cement. (In trench work bailing may be necessary.) Dry it up with a relatively dry concrete. Do not permit the hoisting engineers to continually strike the forming with the concrete bucket. Do not permit direct attachments of machinery to the forms,

as it will result in vibrations which may be detrimental to your face work.

"Use soupy concrete when placed in water; and in muddy water, try to carry the concrete work on continuously; otherwise you will have layers of laitance and mud from ⅛-in. to 1 in. or more in thickness, which are weak and will result in the settlement of your completed structure.

"In one case on my work the top of concrete which was used for sealing the bottom of a cofferdam, and which had been left for about ten days before the cofferdam was pumped out, was found to contain a great deal of this class of rotten material. The bottom of the cofferdam or the top of the seal was very rough; and in the valleys, which varied from 2 to 3 ft. in depth, I found as much as 8 in. of this useless material.

"Don't shovel concrete into water. Place it in as large batches as practicable, and lower with bucket or pipe.

"Don't dump large quantities of concrete into narrow forms. You will not be able to get sound facing work if you do.

"**General Points on Concreting.** Clean all loose silt, dirt, and grease from iron. Use wire brushes and putty-knives.

"Use soupy concrete for concrete-steel work.

"Use rammers having special shapes where necessary. Bevel rammers are necessary for the backs of arches. Railroad tampers for heavy steel reinforcements. Short-handled rammers in confined places, and long-handled rammers in columns. Fine stone forks are better than spades on plain face work where the concrete stones are as large as 2 in.

"It ought not to be necessary on first-class work to be continually patching up. Arrises and corners cannot be patched up except by cutting out large sections of the work. Plastering which is put on finished

work will not hold unless it is put in very thin layers, and then it is doubtful. Corners can never be satisfactorily patched up by plastering. Good work sometimes may be executed on plane surfaces by first wetting the wall and then rubbing on it a coating from 1/16-in. to ⅛-in. in thickness. It takes a good deal of rubbing to get any results; and too much rubbing generally results in hair-cracking, as excessive cement is worked to the surface. The less cement is rubbed, the less hair-cracking will result. No kind of mortar facing should be richer than 1 : 3, and when cast in place it may be as little as 1 : 4 for plane surfaces; ornamental work should not be leaner than 1 : 3. If conditions are such that plastering a veneer on finished work is necessary, I would use a mortar which was already partially set up; then add water, and retemper. The reason that plastered work breaks off, is that the mortar in setting up shrinks. The richer it is, the more it shrinks, and the shrinkage results in leaving a hair-plane between the plaster and the concrete work. The frost does the rest.

"Don't leave timber work in the concrete unless it is absolutely necessary.

"Note any movement or bulging of the form. Correct, if necessary, by wedging, and remodel other similar forms to overcome this trouble.

"Bear in mind that an excess of water weakens the concrete a little, increases efflorescence, and retards the time of setting.

"In work where it is necessary to throw a heavy load upon it in a short time, reasonably dry concrete should be used. Tests indicate that it is probable that wet concrete will be as strong as dry concrete in a year. However, wet concrete certainly bonds the new work better to the old work, and is particularly valuable when encasing steel, as the air is excluded and the steel becomes coated with cement. Excess of water, however, not only results in excess of efflorescence, but also in

the amount of laitance or slime which appears on the surface of a day's work.

"In a batch mixer (excepting the Haines gravity mixer) it does not make any practical difference as to the order in which the material is entered, excepting that the water should be last. The mixer should be kept clean, which means that it should be cleaned every night. The water should be varied with the amount of moisture in the sand and the stone, and should be greater for porous stone. Remember always that after a rain you need less water in your concrete. The amount of sand should be varied also, so as to get a uniform product with run of crusher. This is a very vital point.

"The permeability of concrete may depend upon the cement, but it is certain that it is greater with a dry concrete, and less with a well-graded sand and with a sand containing silt. While 10 per cent and even 15 per cent of silt may be desirable for concrete having a low permeability, it is probable that any amount over 10 per cent weakens concrete, and it is certain that it increases the amount of efflorescence and slime which rises to the surface of a day's work.

"Inspectors on my work use hand-tallying machines to keep track of the number of batches, and at noon and quitting time they check their tally with the bags at the mixer.

"On finished work which is not to be tooled, the lagging should be coated with linseed oil. Glycerine leaves a fatty stain. On work which is to be tooled, it is not necessary to use oil.

"Concrete dumped from large buckets should be lowered as near to the concrete as practicable, particularly when deposited on concrete which is not older than 48 hours, so that the bond between adjacent layers will not be broken.

"The most noticeable imperfection in concrete surfaces is the lipping between consecutive day's work.

The stiffer the forms, the less the lipping. On account of this lipping, I bring each day's work to a horizontal layer by using a straight edge. In mortar facing, I find that if extreme care is not taken the steel plate which is ordinarily used between the concrete and the mortar facing drags, leaving an unreasonably large space between the two; and if the rammers are not particularly careful, there will be no bond between the two, and the mortar facing will flake off.

"A great many so-called concrete workers and concrete contractors do not attempt to cast fine arrises, but assume from the start that they will fix up the work by plastering after the forms are removed. Occasionally your details will not turn out as well as they should, and under such circumstances a thin veneer of mortar is permissible, but should be applied only by an expert concrete finisher. Rubbing finished concrete with grout or painting the face with grout is deprecated. The writer once got hold of several barrels of cement rich in free lime, which he unfortunately used to paint a concrete bridge in order to give it an even finish. The results were very disastrous, and the bridge was a mass of blotches, varying between white and a dirty pink.

"Where it is necessary to cast a cornice in place, the top surface of which is comparatively flat, it is impossible to get this finish against a top form. I would leave the top form off, tamp carefully to grade, and, as soon as the concrete has a fairly good set, from 3 to 12 hours, I would rub it down to an even grade with a small flat stone or a wooden float. In my judgment, it is not desirable to add any additional mortar to make this finish. However, if you have got a poor job on this part of the work and you are practically forced to rub it up, using additional mortar, I would roughen it slightly with a mason's ax, wet it thoroughly, and rub a coat of not more than ⅛-in., using a 1 : 3 cement mortar which has been set up three or four hours.

"Work in Cold Weather. Don't use frozen materials for concrete work. By cutting off the crust of stone or sand, you will get unfrozen material. All hard lumps should be thrown out. When concreting below the freezing point, the stone and sand should be heated, preferably with a coil of steam pipe or with a steam jet inserted at the points where the material is being removed. In this connection, however, it is well to remember that if the material so steamed is not used at once it will give you more water and therefore more ice to contend with in your pile. With a little care you should be able to place your concrete in the work at a temperature of 60° F., regardless of the temperature of the surrounding atmosphere.

"In the winter time it is well to cut down the area of your concrete work by use of bulkheads, so as to decrease the time of exposure of a single layer, which, of course, will result in running your work up to a greater height for a day's work, thereby necessitating stronger forms. There is no trouble at all in executing heavy masonry work, particularly below ground, in the coldest weather, if your materials are heated. However, in thin work (walls under 2 ft. in thickness) it is somewhat dangerous below 25° F.

"Where you have a spaded or mortar finish, extreme care should be taken to protect the work, preferably by covering the outside of the studs with a layer of tar paper. This makes an ice-box sort of arrangement, leaving an air-space of the thickness of your studs between the paper and your lagging. Care should be taken to tack this paper on securely, as it is not infrequent to see paper used in this manner blown off before your concrete has had time to set. Remember that cold weather retards the time of setting of concrete. I have known a number of cases where the time of setting was two or three times as long as in hot weather. This, of course, does not apply to mass concrete.

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T CONSTRUCTION.

"On thin work I would suggest limiting the time of concreting to 28° on a rising thermometer, and 32° on a falling thermometer. On particular work (thin work) I have found the forecast of the Weather Bureau of great assistance in determining whether or not it would be advisable to concrete. During three months of the winter when I was carrying on a very careful piece of work, I found the minimum temperatures predicted by the Weather Bureau very accurate indeed.

"Where I have used tar paper on the outside of trimming, I have found the temperature of the air between the paper and the lagging from 8° to 10° warmer than the outside air at its minimum temperature; and it is well to bear in mind also that the side from which the wind blows is more liable to be frozen than the sides that are protected from the wind. In my own work I take special pains to protect the north and west side of the structure.

"When concreting at low temperature, particularly with a mortar facing, I would suggest to the inexperienced engineer cutting out small blocks of the lagging, say, 4x12 in., at different points of the most exposed sides of the work, in order to note whether or not the mortar facing is being affected by frost. One morning, when the temperature at 8 a. m. was 10° above zero, with a stiff wind blowing, I found the temperature of the air between the paper and the lagging to be 20°; and, upon cutting out the several blocks of lagging, I found a few ice crystals on the inside of the lagging, but the mortar facing was warm and was not affected at all. The temperature of the concrete at placing was about 60°. The temperature of the air at the time of concreting was probably a little below 30° F. This same morning I took off from the top surface two layers of cement bags which had been used to protect the top surface of the concrete, and found the bags frozen, and ice crystals on the under side of the bags. At two or

three spots where the bags had not been properly lapped the concrete was frozen to a depth of 1 in. The balance of the concrete was not affected by frost.

The specifications given below are an example of an attempt made by a municipality to standardize reinforced concrete bridge construction.

SPECIFICATIONS FOR DESIGN OF CONCRETE BRIDGES

Bureau of Surveys, Department of Public Works, Philadelphia

Data for Calculation. The structure shall be proportioned to carry the dead load—consisting of the weight of the structural material, driveway and sidewalk formation, rails, curbs, and railings—and one of the following classes of live load:

A uniformly distributed load over the entire surface, including driveway and sidewalks, as follows:

For spans up to 75 feet, 100 pounds per square foot.

For spans over 75 feet and not over 150 feet, 90 pounds per square foot.

For spans over 150 feet, 80 pounds per square foot.

Sidewalk brackets, joists, and floor to be proportioned for a local loading of 110 pounds per square foot.

A concentrated moving load as follows:

For bridges with permanent pavement on metal deck, a load of 40 tons equally distributed on four wheels spaced 20 feet between axles, and 6 feet gauge.

The following weights are to be used in computing the dead load:

Concrete, 140 pounds per cubic foot.

Binder coat, 135 pounds per cubic foot.

Granolithic pavement, 140 pounds per cubic foot.

Asphalt wearing surface, 87 pounds per cubic foot.

Granite block paving, 6 inches in depth, 80 pounds per square foot.

Vitrified brick paving, 4 inches in depth, 50 pounds per square foot.

Woodwork, 4 pounds per foot board measure.

Concrete-Steel. When concrete-steel is used, it shall be so designed that the stresses in the concrete and the steel shall not exceed the following:

	LBS. PER SQUARE INCH.
Extreme fibre stress on concrete compression	425
Direct compression on concrete	300
Shearing stress on concrete	50
Tensile stress in steel	16,000
Shearing stress in steel	10,000

The tensile strength of concrete shall not be considered. The ratio of the moduli of elasticity of concrete and steel shall be taken as 1-12.

The steel rods must be of a design that will provide a mechanical lock with the concrete, and not depend upon the adhesiveness of the cement.

In the determination of bending moments, beams and girders shall be considered as simply supported at the ends, no allowance being made for continuous construction over supports. Floor-plates, when constructed continuous and provided with reinforcement at top of plates over supports, may be treated as continuous beams, the bending moment for uniformly distributed loads being taken not less than $\frac{WL}{10}$; the bending moment, in the case of continuous square floor-plates reinforced in both directions at top and bottom and supported on all sides, may be taken at $\frac{WL}{20}$. The floor-plate to the extent of three times the width of beam or girder, may be taken as part of that beam or girder in computing its moment of resistance.

Concrete-steel may be used for columns in which the ratio of length to least side or diameter does not exceed 12. The reinforcing rods must be tied together at intervals not greater than the least side or diameter of column.

Cement Concrete—Proportions. Cement concrete, unless otherwise specified, shall be composed of 1 part cement; 3 parts coarse sand or gravel or stone screenings; and 6 parts crushed stone. These proportions shall be determined by measurement, a barrel of cement being taken to contain 3.8 cu. ft. and a bag of cement .9 cu. ft.

Sand or Gravel. The sand or gravel or screenings shall consist of grains graded from coarse to fine, containing not more than 5 per cent by weight of loam, clay, dirt, and other impurities, and be equal in quality to the best New Jersey bank sand or gravel.

Crushed Stone. The stone shall be clean, hard, cubical, crushed natural stone or crushed pebbles to be approved by the Chief Engineer, comprising the whole run of the crusher from $\frac{1}{4}$ inch to $\frac{3}{4}$ inch in size when used for bedding on metal decks, or for balustrades or parapets, or for any concrete in which large stone or steel reinforcement is to be embedded; and from $\frac{1}{4}$ inch to 2 inches for other purposes, screened of dust and particles less than $\frac{1}{4}$ inch. Care shall be taken that each batch as used is mixed as to size. No limestone shall be used in arches over steam railroads.

Storage piles of material shall be on a platform or other hard, clean surface, to avoid admixture of dirt.

Mixing. Mixing of materials shall be done by machine whenever practicable, and always in batches. When mixed by hand, the cement and sand shall be first mixed dry, and then made into mortar by gradually adding clean water and hoeing or otherwise working until a uniform mixture is secured. The stone shall be spread upon a suitable floor to a depth of about 6 inches, and thoroughly wetted, and the mortar evenly spread over it. The whole mass shall then be turned over four times, and raked to secure complete and uniform mixture. If the Contractor desires to use some other method, he must submit it for approval. Concrete shall be kept in motion until deposited in place. Should any be permitted to set before placing or tamping, it shall be removed and

not used. Hand-mixed batches shall not be larger than 1 cubic yard in volume.

Preparation of Surfaces. Surfaces upon which concrete is to be deposited, whether of old masonry or of concrete layers, shall be thoroughly cleaned and wetted, and coated with a complete layer of cement mortar.

Depositing. Concrete shall be deposited in layers not more than 6 inches in depth, and compacted by tamping if necessary until flushed. When used for foundations, it shall, where practicable, be deposited and rammed against the sides of the excavation. In the abutments of arches, the layers shall be sloped as nearly as possible normal to the direction of the line of thrust of the arch. In other abutments and retaining walls, the courses shall be sloped so as to shed water to the back. Steps at back shall be sloped from the wall 1 inch per foot to shed water.

When concrete is marked on the face into courses, each requiring two or more layers, the layers shall follow each other in close succession, before setting, so as to avoid visible joints in the face of a course.

Joints. In work above ground, the top surface of each course shall be scraped within 24 hours, and swept to remove "laitance" or scum, and insure the adhesion of the next layer.

Embedded Stone. In foundation concrete, approved hard flat stone equal to the best Conshohocken stone of one-man size or larger may be embedded in the concrete, the stones to be separated sufficiently to be each completely encircled by the concrete, and to be not closer than 2 inches to any face of the foundation. In neat work, similar stones, but not larger than two-man size, shall be embedded in each course so as to project up and form dowels bonding the courses together; and no such stone with flat vertical surface shall be closer than 6 inches to the face of the work.

All embedded stone shall have the concrete deposited

first, and shall then be embedded by joggling the stone down in the concrete.

Protection. Finished concrete work shall be protected against disturbance until thoroughly hardened, by preventing working or building upon it; and against the sun, if necessary, by covering and wetting for at least 48 hours.

Granolithic Surfaces. All showing faces of concrete work shall have a granolithic surface. Granolithic surfacing shall be composed of 1 part cement, 1 part coarse sand or gravel, 1½ parts granolithic grit, made into a stiff mortar. Granolithic grit shall be granite or trap rock crushed to pass a ¼-inch sieve, and screened of dust. For vertical surfaces the mixture shall be deposited against the face forms to a least thickness of 1 inch, by skilled workmen, as the placing of the concrete proceeds, and thus form a part of the body of the work. Care must be taken to prevent the occurrence of air-spaces or voids in the surface. The face forms shall be removed as soon as the concrete has sufficiently hardened, and any voids that may appear shall be filled with the mixture. The surface shall then be immediately washed with water until the grit is exposed and rinsed clean, and protected from the sun and kept moist for 3 days. For bridge-seat courses and other horizontal surfaces, the granolithic mixture shall be deposited on the concrete to a least thickness of 1½ inches, immediately after the concrete has been tamped and before it has set, and shall be troweled to an even surface; and, after it has set sufficiently hard, shall be washed until the grit is exposed.

STANDARD RULES FOR BRIDGE MASONRY CONSTRUCTION

The following are outline rules and specifications for the design and construction of bridge masonry, similar to those in use by the large

railroads of the United States at the present day. They are intended to cover only the main features:

General Rules for Masonry Plans

Scale. In general, masonry plans should be made to a scale of about ¼ inch = 1 foot. Details may be drawn to larger scale, and scale should be noted.

Views. As many views should be given as will show the construction of every piece of masonry. In structures which consist of several parts, a diagram should be added showing the relative location and elevation of the different parts.

Dimensions. Dimensions of masonry structures should not be given closer than to quarters of an inch, except the vertical dimensions locating bridge-seats, which should be given to eighths.

Only such dimensions as are necessary for laying out the work in the field or as assist materially in checking the plan, should be noted on drawings. Repetition of dimensions should be avoided.

All corners of footing courses and neatwork lines on footings should be definitely located. All intersections of planes should be definitely located.

Exact batters on inclined faces, as well as determining dimensions, should be given.

All dimensions should be referenced to some definite base line and working point, as the center-line of track or the center-line of structure and their intersection. In skew bridges the center-line of structure should be used.

Piles should be located in rows, the spacing being given perpendicular and parallel to the rows, and the end pile in each row being definitely located.

Elevations and distance from base of rail of all important points in masonry structures, should be given on plans.

General. The directions of the compass are to be taken as given in the time-table—going to Chicago being East and away from Chicago being West. East should always be at the right-hand side or top of the drawing. The directions of the compass should be noted on all drawings.

High-water and low-water and low-steel should be shown to scale, and marked with elevations on substructure plans.

All masonry plans should contain the following information under the heading "General Notes":

Location of structure;
Drawing number of survey;
Bench-mark;
Present elevation base of rail at Sta. ....;
Proposed elevation base of rail at Sta. ....;
Station .... at East end of present bridge;
Grade .... rising ....;
Alignment;
Super-elevation;
High-water elevation;
Low-water elevation;
Bearing on soil;
Bearing on piles;
Falsework;
Drawing number of steelwork.

All masonry plans should contain a bill of material to include cubic yards of concrete, number, size, and length of reinforcing bars, piles, drain-pipes, etc.

Titles of masonry plans on each sheet should give size of span, character and location of structure, and subtitle for that particular sheet.

When there are several sheets to one set of plans, each sheet should be numbered just above the title as two or five, or as the case may be.

Notes on Foundations

Loads on Foundations. The recommendation of the Assistant Engineer regarding the allowable bearing on soil or allowable load on piles, should be followed in the design of foundations.

In case there is no recommendation, the bearing is to be based on the data given on the survey. The following limiting values will serve as a guide:

Rock	10 to 100 tons per sq. ft.
Gravel	3 to 6 tons per sq. ft.
Sand	1 to 4 tons per sq. ft.
Clay	1 to 3 tons per sq. ft.
Mud, loam, gumbo	½ to 1½ tons per sq. ft.

In the absence of recommendation regarding load on piles, 18 tons per pile should not be exceeded.

Proportions of Foundations. The unit-bearing on foundations should be kept the same under all parts of continuous structures. Foundations should be designed to distribute the loads upon them uniformly.

In general, footings for natural foundations should be made 1 ft. 6 in. or 2 ft. thick.

Footings for pile foundations should be made 3 ft. thick, with the pile head projecting 1 ft. into the concrete.

Depth of Footings. Wherever exposed to the action of frost, footings should be carried from 3 ft. to 5 ft. below ground level, depending on the latitude. Footings should be carried to the firmest foundation within reasonable reach.

Pile Spacing. Foundation piles should not be spaced closer than 2 ft. center to center in any direction, and at least 2 ft. 6 in. should be allowed in one direction.

Reinforced Concrete Design for Bridge Work

Reinforced concrete structures shall be designed ac-

cording to the following methods, assumptions, and unit-stresses.

Loading. The dead loads for which concrete structures are designed, shall consist of the weight of the structure, the fill, and the track. Reinforced concrete shall be assumed to weigh 150 lbs. per cubic foot, and earth 100 lbs. per cubic foot.

The specifications regarding live loads, wind loads, tractive force, etc., shall be the same as given in the "Standards for Steel Structures," with the addition of the following paragraph:

"When the ballast or fill under base of rail on a concrete structure is less than two feet, the wheel loads shall be considered as concentrated along the track, and as either concentrated or distributed over eight feet transverse to the track, according to which of the latter assumptions gives the greater stresses. When the fill is more than two feet, an equivalent uniform load shall be used, distributed over eight feet at the base of rail, and spreading transversely six inches per vertical foot through the fill and twelve inches per foot through the concrete. The equivalent uniform load shall be assumed as 12,000 lbs. per linear foot of track for spans under twenty feet, and equivalent to standard E-55 loading for spans over twenty feet.

Impact. An impact allowance of 50 per cent shall be added to all live loads.

Coefficients of Elasticity. The ratio of the coefficient of elasticity of steel to the coefficient of elasticity of concrete shall be assumed to be twelve. This ratio is based on an initial coefficient in the concrete of 2,500,000, and a steel coefficient of 30,000,000.

Factors of Safety. A factor of safety of at least three and one-half shall be allowed in concrete structures.

Unit-Stresses. The following unit-stresses shall be al-

lowed in the concrete of reinforced structures unless otherwise noted in these standards:

(Concrete, 1:2.5:5 or better)

	Lbs. per Sq. In.
Direct compression	500
Compression on extreme fiber in beams under flexure	750
Shear; true shear not combined with flexure	200
Shear; combined with flexure	30

The maximum allowable tension in reinforcing steel shall be not more than one-third the elastic limit, and shall in no case exceed 15,000 lbs. per square inch.

Shear. In members under flexure, the average vertical shear shall not exceed thirty pounds per square inch where no web reinforcement is provided. Where reinforcement is provided, the average vertical shear shall not exceed seventy-five pounds per square inch.

Where web reinforcement is necessary, it shall be designed to carry all of the web stresses.

Web reinforcement shall consist of bent-up bars, or stirrups, or both. The bars or stirrups shall be spaced not farther apart in the direction of span than the depth of the beam; they shall be hooked to the reinforcement on the tension side of the beam, and they shall be made sufficiently long to develop their strength in bond.

Bond. The following values for bond between concrete and steel shall be used:

For plain bars	60 lbs. per sq. in.
For deformed bars	100 lbs. per sq. in.

Bars shall be lapped or imbedded at least 60 times their thickness or diameter if plain, and at least 40 times if deformed.

Temperature Stresses. Concrete structures shall be

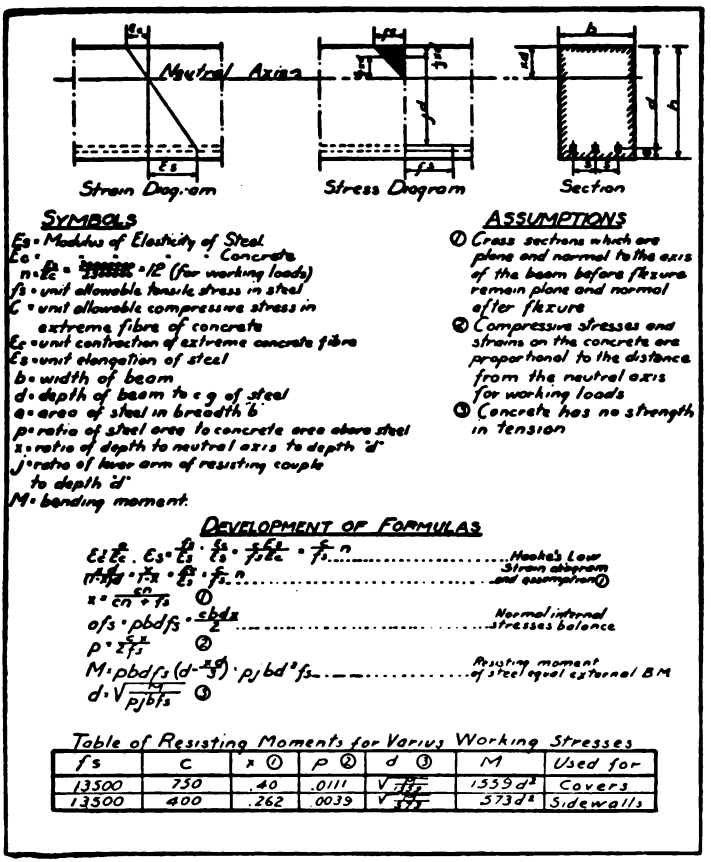

Neutral Axis
Strain Diagram
Stress Diagram
Section
SYMBOLS
Es = Modulus of Elasticity of Steel
Ec = " " " Concrete
n = Es/Ec = 12 (for working loads)
fs = unit allowable tensile stress in steel
C = unit allowable compressive stress in extreme fibre of concrete
εc = unit contraction of extreme concrete fibre
εs = unit elongation of steel
b = width of beam
d = depth of beam to c.g. of steel
a = area of steel in breadth b
p = ratio of steel area to concrete area above steel
x = ratio of depth to neutral axis to depth d
j = ratio of lever arm of resisting couple to depth d
M = bending moment
ASSUMPTIONS
① Cross sections which are plane and normal to the axis of the beam before flexure remain plane and normal after flexure
② Compressive stresses and strains on the concrete are proportional to the distance from the neutral axis for working loads
③ Concrete has no strength in tension
DEVELOPMENT OF FORMULAS
Hooke's Law
Strain diagram and assumption ①
Normal internal stresses balance
Resisting moment of steel equal external BM

Table of Resisting Moments for Varius Working Stresses

fs	C	x ①	p ②	d ③	M	Used for
13500	750	.40	.0111	$V\frac{M}{.1539}$	$1539d^2$	Covers
13500	400	.262	.0039	$V\frac{M}{.573}$	$.573d^2$	Sidewalls

Fig. 81. Formulas for the Design of Reinforced Concrete Beams.

designed to provide for a variation in temperature of 50 degrees Fahrenheit—15 degrees rise and 35 degrees fall. The coefficient of expansion shall be taken as .000,005,5.

If expansion joints are not provided, sufficient steel shall be used to provide a tensile resistance (at an elastic limit stress) equal to the tensile resistance of the concrete section (at 200 pounds per square inch).

Longitudinal Reinforcement. In all slabs or walls, re-

TABLE III

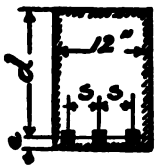
Moments, Depths, and Areas of Steel, and Spacing of Bars

Formulas—

$$d = \sqrt{\frac{M}{1559}}$$

$$a = .0111 \times 12 \times d$$

Formulas based on allowable unit stresses of 750 lbs. per sq. in. on concrete and 18,500 lbs. per sq. in. on steel. 50% must be added to Live Load moments.



e=1½ in. for ½ in. sq. bars
e=1¾ in. for ¾ in. sq. bars
e=2 in. for 1 in. sq. bars

When S is less than 4 times dimension of bar a double row must be used.

Resisting Moment in thousands in.-lbs.	d (in.) Depth to Steel	a(sq.in.) Area of Steel per Foot Width	Spacing c to c for ¾ in. Sq. Bars	Spacing c to c for ½ in. Sq. Bars	Spacing c to c for 1 in. Sq. Bars
14	3	.40	16¾	7½	30
19	3½	.47	14½	6½	26
25	4	.53	12½	5½	22½
31	4½	.60	11¼	5	20
39	5	.67	10	4½	18
47	5½	.73	9¼	4	16½
56	6	.80	8½	3¾	15
66	6½	.86	7¾	3½	14
76	7	.93	7¼	3¼	13
88	7½	1.00	6¾	3	12
100	8	1.06	6¼	2¾	11¼
113	8½	1.13	6	2½	10½
126	9	1.20	5½	2½	10
141	9½	1.27	5¼	2½	9½
156	10	1.33	5	2¼	9
172	10½	1.40	4¾	2¼	8½
189	11	1.47	4½	2	8¼
206	11½	1.53	4¼	.....	7¾
224	12	1.60	4¼	.....	7½
244	12½	1.67	4	.....	7¼
264	13	1.73	3¾	.....	7
284	13½	1.80	3¾	.....	6¾
306	14	1.86	3½	.....	6½
328	14½	1.93	3½	.....	6¼
350	15	2.00	3½	.....	6
400	16	2.13	3¼	.....	5½
452	17	2.26	3	.....	5¼
505	18	2.40	.....	.....	5
563	19	2.53	.....	.....	4¾
624	20	2.66	.....	.....	4½
688	21	2.80	.....	.....	4¼
755	22	2.93	.....	.....	4
823	23	3.06	.....	.....	4
897	24	3.20	.....	.....	3¾
975	25	3.33	.....	.....	3½
1,054	26	3.46	.....	.....	3½
1,139	27	3.60	.....	.....	3¼
1,221	28	3.73	.....	.....	3¼
1,311	29	3.86	.....	.....	3¼
1,404	30	4.00	.....	.....	3
1,499	31	4.13	.....	.....	3
1,593	32	4.26	.....	.....	2¾
1,700	33	4.40	.....	.....	2¾
1,802	34	4.53	.....	.....	2¾
1,910	35	4.66	.....	.....	2½
2,020	36	4.79	.....	.....	2½
2,135	37	4.93	.....	.....	2½
2,256	38	5.06	.....	.....	2½

inforcement in a direction at right angles to the main reinforcement shall be provided, such reinforcement to have a sectional area of about 1-900 of the concrete area.

Bending Moments. All beams and slabs shall be assumed as freely supported simple beams in calculating positive bending moments; but negative moments of approximately one-half the theoretical shall be provided for (at working stresses).

Detailing Reinforced Concrete for Bridge Work

Drawings. Plans and details of reinforced concrete structures shall show the size, length, and exact location of all reinforcing material. In general, the sizes and lengths shall be shown on the elevations and the spacings on the cross-sections.

In highly reinforced work, the concrete dimensions and the reinforcement details shall be shown on separate views. Large-scale cross-sections and diagrams shall be added where the bar arrangement is complicated.

Bending diagrams shall be shown for all bent bars, and such bars shall be given some reference mark.

Lengths of Bars. Bars shall be called for in lengths which can be cut from stock lengths with minimum waste. Bars shall be called for in even feet or half-feet wherever possible. As few different lengths as possible shall be used.

Spacing of Bars. Bars shall be spaced not closer than four diameters center to center, and not farther apart than the depth of the beam or slab. The bars shall be chosen of such a size that the spacing will be, preferably, about 6 to 9 inches.

The distance from the surface of the concrete to the center of the bar shall be at least the thickness of the bar, plus one inch.

Bends in Bars. Unnecessary bends, bends in heavy bars, and many bends in the same bar shall be avoided. Small-sized bars of low elastic limit shall be used for stir-

rups and for reinforcement which must be bent to a small radius.

General. In the design and arrangement of reinforcement, due regard shall be given to the cost and difficulty of construction.

Billing of Bars. All reinforcing material shall be listed in a "Bill of Reinforcement," showing number, size, length, mark, and location. The material shall be listed in the order in which it is put into the structure—material in the footings to come first, etc. Large numbers of bars of varying lengths, as in wing-walls, may be billed in total linear feet; but lengths should be noted on plan.

Specifications for Concrete Bridge Masonry

Concrete masonry must conform to the following specifications:

1. **Cement.** All cement shall be Portland cement, and shall conform to the specifications of this department. The brand shall be approved by the Engineer.

2. **Sand.** The sand shall be clean and coarse, or a well-graded mixture of coarse and fine grains, with the coarse grains predominating. Sand containing more than 5 per cent of clay or loam shall not be used until tested and its use approved by the Engineer.

3. **Gravel.** The gravel shall contain no stones over two inches in diameter, and not over 30 per cent of its volume shall be too large to pass through a screen having one-quarter-inch meshes. The sand in the gravel shall conform to the requirements for sand specified above.

4. **Stone.** The broken stone shall be from sound, hard, and durable rock, such as trap, limestone, or granite; clean and free from foreign substances; and shall be composed of angular fragments of the following sizes:

(a) Two-inch stone, containing everything that will pass through a ring two inches in diameter, and screened until none of it will pass through a screen having one-quarter-inch meshes.

(b) One-inch stone, containing everything that will

pass through a ring one inch in diameter, and screened until none of it will pass through a screen having one-quarter-inch meshes.

(c) One-half-inch stone, containing everything that will pass through a ring one-half inch in diameter, and screened until none of it will pass through a screen having one-quarter-inch meshes.

When, in the judgment of the Engineer, the character of the work will permit, it shall be unscreened and crusher-run. In this case, everything that will pass through the required size ring is wanted just as it comes from the crusher, provided it contains no foreign substances. An artificially mixed crushed stone will not be accepted.

5. **Water.** The water shall be clean and free from acids or strong alkalis.

6. **Classification.** Concrete masonry will be of three classes, determined by the proportions of the materials, as follows:

Class A—Concrete made in the proportions of one sack of cement to 2½ cubic feet of sand and 5 cubic feet of broken stone.

Class B—Concrete made in the proportions of one sack of cement to 3 cubic feet of sand and 6 cubic feet of broken stone.

Class C—Concrete made in the proportions of one sack of cement to 3½ cubic feet of sand and 7 cubic feet of broken stone.

In general, the class of concrete to be used in any given structure will be stated on the masonry plan; but, when not stated, will be as follows unless otherwise directed by the Engineer-in-Charge:

Class A concrete will be used in the covers of culverts, arch-rings, copings of piers and abutments, foundations laid under water, walls subject to water pressure, when

BUSH TRAIN SHED AT SCRANTON, PA.

COAL HOPPER FOR CENTRAL HEATING COMPANY, DETROIT, MICH.

PLATE 18—CEMENT CONSTRUCTION.

View from water, showing boat entrance.

View from land, showing entrance to garage.

CONCRETE BOAT HOUSE AND GARAGE.

PLATE 19—CEMENT CONSTRUCTION.

desired to make impervious, and for all concrete which is fully reinforced.

Class B concrete will be used in retaining walls, piers, abutments, pedestals, foundations subject to vibration, walls, footings of structures where piles are used or where a wet foundation is encountered, and in all concrete that is only partially reinforced, provided this classification does not conflict with the conditions specified for Class A concrete.

Class C concrete will be used in the footings of structures on dry foundations, and in the neatwork of unimportant structures.

7. **Proportioning.** One sack of cement (one-fourth of a barrel) is taken as the unit of measurement, and assumed as containing one cubic foot.

The sand and broken stone in each batch shall be accurately measured by volume in boxes, or by frequently checked gauge-marks on the barrows or cars. Gravel may be used in place of sand, in which case the amount of pebbles exceeding one-quarter-inch in diameter, in the gravel, is to be determined by screening, and the relative proportions of gravel and broken stone changed to correspond.

8. **Consistency.** For concrete fully reinforced, thin building walls and columns, a mushy concrete, so soft that it must be handled quickly or it will run off the shovel, should be used.

For ordinary mass concrete, such as large walls, foundations, piers, and abutments, use a medium wet concrete of such consistency that when dumped into place it will not require tamping, and will be wet enough to cause the workmen to sink into it ankle deep.

9. **Hand-Mixing.** If the concrete is mixed by hand, it shall be done as follows: The sand or gravel and cement shall be thoroughly mixed dry by being deposited in alternate layers on a water-tight platform, and then turned with a shovel or a hoe not less than twice, so that

the mass will be of a uniform color, showing no streaks of sand, after which the amount of water required shall be added, and the mass again mixed to a uniform consistency.

In the meantime, the broken stone shall have been spread on a water-tight platform in a thin layer and wetted down. On this thin layer of stone, the mortar is to be uniformly spread, and the mass turned with shovels until each particle is entirely surrounded with mortar and the mass is of a uniform consistency before it is shoveled into the barrows.

10. **Machine-Mixing.** If the concrete is mixed by a machine, the machine shall be of a design approved by the Engineer. The size of each batch mixed shall not exceed the rated capacity of the mixer; and no batch will be discharged from the mixer until a sufficient number of revolutions have been made after all of the ingredients have been deposited in the mixer to insure a first-class concrete of uniform consistency. The use of a continuous mixer will not be permitted.

11. **Placing.** The concrete shall be conveyed and deposited in such a manner that there shall be no distinct separation of the different ingredients, and shall be used so soon after mixing that it can be worked or puddled in place as a plastic, homogeneous mass.

All exposed surfaces and those required to be waterproofed shall be well spaded, to force back the broken stone and secure a finished mortar surface; and in all cases the entire mass shall be puddled and worked as deposited, so as to expel the air and surplus water.

So far as possible, the work shall be carried on continuously—that is, with the least number of joints practicable; and in no case must the concreting be stopped within eighteen inches of the top of a wall.

Whenever it becomes necessary to allow one layer of concrete to set before the next one is placed, the exposed faces adjacent to the form shall be leveled off with a

trowel or by setting in a straight plank so that the joint will be parallel to the cracks in the form. Back from the face, the top of the concrete should be left rough and irregular. Boulders, heaps of concrete, or depressions made by inserting timbers, should be left on this surface to insure a good bond.

Before the next layer of concrete is started, the form shall be thoroughly tightened to prevent overhanging joints; and the inside surface of the forms shall be cleaned. The old surface of concrete should be thoroughly wet, and a layer of mortar placed over it, before depositing additional concrete. Particular care should be taken to use mortar along the face so that no joint will be perceptible.

The footing and neatwork must be thoroughly bonded together in a manner similar to that described above for other horizontal joints.

Where it is necessary to stop placing concrete before any course is finished, use a bulkhead of boards at the stopping place, to obtain a vertical joint.

Where the laying of concrete is stopped on the slopes of abutment wings, a feather-edge must be avoided by making a joint at right angles to the slope. This can be accomplished by using a plank properly placed, behind which the concrete must be thoroughly rammed.

Bridge-seats and all places requiring a bearing surface should be leveled off with a float, and troweled, to secure a sidewalk finish.

12. **Freezing Weather.** Only concrete that is laid in large masses should be placed in freezing weather, and no concrete work of any kind should be carried on when the temperature is lower than 15 degrees above zero, except where it is deposited in water or below the surface of the ground. Whenever concreting is done in freezing weather, the water, sand, and broken stone must be heated and all frost removed before they are used; and concrete, when deposited in the forms, must be protected

from alternate freezing and thawing by some method approved by the Engineer-in-Charge.

13 **Reinforced Concrete.** Where concrete is placed in connection with reinforcing metal, care must be taken to locate accurately all bars in strict accordance with the plans, and they should be wired together in such a manner as to avoid any possibility of their being displaced when the concrete is deposited.

The steel used shall be clean, and free from dirt, oil, paint, or injurious rust.

In general, no reinforcing bars larger than one inch in diameter will be used; and these may be bent cold, when necessary, about a radius of not less than six inches.

Reinforced concrete work should be as far as possible monolithic, but when joints are necessary, they shall be made at such points and in such a manner as to meet the approval of the Engineer-in-Charge.

In reinforced beam work, such as floor beams, floor slabs, or culvert covers, the bars should be first entirely surrounded with a cement mortar composed of one part cement to two parts sand, with the concrete deposited immediately afterwards.

14 **Forms.** The following sizes of lumber are to be used in the construction of forms for concrete masonry:

SPECIFICATIONS FOR CONCRETE BRIDGE FLOORS

3x 6	12' to 16' lg	S1F	Posts and Girts
1x 8	12' to 16' "	S1S2E	Facing
2x 8	12' to 16' "	S1S2E	Facing
2x 8	12' to 16' "	D & M	Sheet Piling
4x 6	12' to 16' "	Rough	Bracing
2x10	12' to 16' "	"	Runways &
3x10	14 to 18 "	"	Platforms
S. H. Stringers and ties			Cofferdam frames

In general, 1x8, surfaced on one side and both ends (S1S&2E), should be used for facing, with joints breaking as much as practicable without unnecessary waste of

lumber; 2x8's, S1S&2E, should be used for facing only where it is important to obtain a good-appearing face, or where additional strength seems necessary.

For 1x8 facing, the 3x6 posts should be spaced about two foot centers, held in line by girts of the same size material.

The forms should be tied together in accordance with Drawing ——, using form castings —— and No. 10 annealed wire. They must be thoroughly braced to prevent crowding out of line, and must not be removed until the concrete has hardened sufficiently so that it will not flake off.

One and three-quarter-inch cove moulding should be used on all exposed corners.

SUPERINTENDENCE AND INSPECTION

The Florida East Coast Railway, which built the famous viaduct of concrete arches along the Florida Keys, to which reference has already been made, issues the following instructions to its inspectors on concrete work:

Inspectors will be required to become familiar with, and carefully follow out, the following instructions regarding inspection, and see that the work is carried out in strict accordance with same. An inspector will be required to be on the work during the setting of forms, placing of reinforcement, and the mixing and placing of concrete. He will represent the Engineer-in-Charge, and will be held responsible for the correct performance of the work assigned to him. He will, in a general way, carefully and continuously watch the progress of the work, making a record of the amount of work done each day and the manner in which it is done.

He will be required to become thoroughly familiar with the plans of the work which he is inspecting, that he

may intelligently perform the duties intrusted to him. He will be required to fill in a daily report sheet, printed forms being furnished for this purpose, giving the location of the work, the amount of work done, the number of batches mixed and placed, the proportions used, the arrival of material, and all such other information as will assist in making a concise and accurate record of the progress and cost of the whole or any part of the work.

He will see that the following specific instructions are carried out:

Forms. That the forms are properly set up and braced.

That the concrete face of the forms are given a coat of oil, applied with a brush.

That an excess of oil is not used.

That the forms are cleaned at each setting and recoated with oil.

That the forms are correctly placed, allowing the depth, width, and batter called for on the plans.

That the inside of the forms is free from debris (shavings, sawdust, blocks of wood, etc.) just previous to pouring.

That the forms are properly held together with No. 9 wire or rods of suitable dimensions, and temporary spacing pieces are used and removed when the concrete reaches their height.

That the joints formed by the edges of the lagging are tight, so that grout will not escape, and that such defects are remedied by the use of Plaster of Paris, calking, strips of wood, or other suitable approved method.

That the arch centers are lowered sufficiently to allow the arch-ring to assume its permanent set before spandrel walls are poured, in this manner reducing the possibilities of cracks occurring in spandrel walls, because of possible excessive settlement in crown of arch-ring.

Steel Reinforcement. That the correct number and

size of reinforcing bars are used, and that they are placed as shown on plan.

That all steel used is free from loose or scaly rust. (A thin film of rust will not cause the rejection of a bar.)

That bars covered with loose, scaly rust are cleaned with a stiff wire brush, or given a pickling bath of a sulphuric acid solution (consisting of 1 part acid to 6 parts of water) and dipped in clean water.

That the intersections of the rods are wound with a length of No. 18 wire in a sufficient number of places so that the whole steel reinforcement will be fabricated sufficiently strong and rigid to withstand the placing of concrete about the steel and without disturbing the position of same.

That the bars are spaced the proper distance apart and away from the face of the form work, and are secured properly and held in that position in such a manner that they will not be disturbed by the placing of concrete.

That all protruding bars from piers and arches to which other bars are to be spliced and which will be exposed to the action of the weather for an indefinite period are protected from rusting by a coat of thin, neat cement grout.

That the position of the steel is not disturbed during pouring.

Placing Concrete. The inspector will see that the specified proportions of material are used in mixing the concrete.

That the concrete is of the proper consistency.

That an accurate account is kept of the number of batches mixed, the same to be recorded on a printed card which will be furnished for that purpose.

That these batch record cards are preserved and filed for future reference.

That in placing the concrete the same will be done in a careful manner, and precautions taken not to allow the concrete bucket to come in contact with the form work.

That care is taken not to jar the form work until the concrete work is hardened.

That in making a bond between old and new work care is taken to thoroughly clean the surface of old concrete (preferably by a jet of steam), and that a thin layer of a 1 to 1 grout is spread to assist in making a good bond.

That the surface of the concrete which is to be bonded to other concrete is left in a rough condition, either by spreading a layer of broken stone over the same, running half the depth of the stone into the green concrete, and leaving the upper half of the stone protruding, or by setting in strips of wood, which, when removed, will form a groove and assist in making a good bond.

That in bonding the spandrel wall with the arch-ring, a groove or ridge is formed on arch-rings running under and with spandrel wall, to prevent water from center filling to run through and down the face of arch-ring, discoloring same.

That in placing dry concrete the same is thoroughly compacted with suitable approved iron tamps.

That in pouring wet concrete the same is thoroughly spaded, rodded, and worked with suitable tools sufficiently to cause all air bubbles to escape, to work grout to face of form work, filling all voids, and showing a smooth, well-mixed concrete free from voids when forms are removed.

That a fine mixture of 1 to 3 is deposited around and among the bars, and that it is thoroughly worked in and around the bars in such a manner that the steel will be completely surrounded, embedded, and covered.

That all concrete is deposited in forms within 30 minutes after leaving mixer.

That all exposed surfaces of concrete are kept continually wet for a period of ten days after removal of forms.

In General. A record book will be furnished the inspector, in which a record will be kept of the progress of

the work, and the following information should be recorded: Date; time of day of each entry; day or night work; number of men; foreman; condition of forms; condition of steel; number and location of lights (if night work) and if properly lighted; number, time and location of test cubes taken; rate of mixing; size and number of batches; proportions of mixture; name or number of work barge; arrival of material; kind and amount and on what barge.

Inspectors will be required to fill in several daily report blanks that will be furnished.

Inspectors will receive further written instructions from the Engineer-in-Charge from time to time, and will attach same to these instructions and will consider them a part of same.

Care should be taken not to allow the first concrete placed to appreciably stiffen or set before the remaining concrete is placed. The remedy for this is to add occasionally, as often as is necessary, a little more concrete to that already placed over all exposed surfaces.

Great attention is necessary to make each section (pier, arch-ring, or spandrel wall) monolithic in height, length, and width. Only when circumstances render it practically unavoidable, may the work be stopped before the entire section is completed.

Order and close attention to details is essential. Carelessness in proportioning, in mixing or compacting the materials, or the omission or misplacement of the steel bars, may cause defective or even destructive results. Reinforced concrete construction requires close, continuous, and intelligent supervision.

SPECIFICATIONS FOR MATERIALS AND LABOR

The following brief specifications for materials and labor in bridge and culvert construc-

tion, issued by the Corrugated Bar Company, of St. Louis, may be regarded as typical of standard modern practice:

Specifications for Materials and Labor

Cement. Only Portland cement conforming to the requirements of the specifications adopted by the American Society for Testing Materials shall be used.

Sand. Sand to be clean and coarse, and free from organic matter; a graded sand, with coarse grains predominating, is to be preferred.

Coarse Aggregate. Broken stone to be hard, durable limestone, or its equivalent, free from dust and foreign materials; maximum-sized particles to pass through a one-inch ring; fines to be removed by passing over a one-quarter-inch screen. The fines may replace part of the sand. Under special conditions making for uniformity, crusher-run may be used; but this is not desirable.

Gravel shall be clean and of graded sizes; the sand carried to be removed by screening as for broken stone.

Proportions of Mix. Concrete for columns, beams, and slabs to be mixed in the proportion of one part cement to six parts aggregate; proportions by volume taking one bag containing not less than 94 pounds of cement, equal to one cubic foot of cement.

The proportions of fine and coarse aggregate used shall be chosen so as to give a concrete of maximum density; in no case, however, may the amount of fine aggregate be less than 50 per cent of the coarse.

Reinforcing Steel. All reinforcing steel used in bridge and culvert construction shall be rolled to such form that it has a positive mechanical bond with the concrete. Adhesive bond will not be considered sufficiently reliable for this class of structures.

Steel may be made by either the Bessemer or open-hearth process; bars to be rolled from billet stock. Re-

rolled material will be accepted under conditions insuring rigid inspection.

The elastic limit and percentage of elongation shall be determined by tests on accurately-machined specimens, and shall conform to the following requirements:

Elastic limit to be from 50,000 to 60,000 pounds per square inch, ultimate strength not less than $1^1/_3 \times$ elastic limit.

The percentage of elongation in 8 inches must not be less than given by the formula:

$$\text{Percentage of elongation} = \frac{1{,}400{,}000}{\text{Ultimate strength}} - 5.0.$$

Bending Test. Bars as rolled shall bend cold, 90 degrees, to a radius equal to three times the least diameter of the specimen, without sign of fracture.

Forms. Forms must be smooth and true to dimensions, with close joints to prevent leakage, and must be of sufficient strength to carry the load without appreciable deflection.

Removal of Forms. The time of removal of forms should be left to the discretion of the engineer, as the time required for the concrete to gain sufficient strength is dependent upon temperature and weather conditions and on the particular cement used. Forms for slabs should not be removed in less than two weeks under the most favorable conditions; girder forms should not be removed in less than three weeks.

Mixing. Machine mixing is to be preferred in all cases—hand mixing to be allowed at the discretion of the engineer. Concrete for reinforced work shall be mixed wet, sufficient water being used to make a mass that will flow readily and be of such consistency that the reinforcing steel will become coated with a protective coat of fluid mortar. Excess of water should be avoided, as it tends to a separation of the parts.

Placing. In girder bridges and in all T-beam designs,

the concrete must be placed the full depth (to the top of the slab) at one operation. If possible, the work should be carried on continuously to completion.

COMPARATIVE COST OF CONCRETE BRIDGES

The cost of concrete bridge construction is of especial interest when compared with the cost of bridge construction of wood, steel, stone, or other material, because it is the constant endeavor of engineers and contractors to find the cheapest form of construction which will meet the requirements. To answer its purpose, a bridge must not only satisfy present requirements but be of sufficient durability to keep maintenance and depreciation charges reasonably low. A paper read by Mr. E. P. Goodrich before the National Cement Users' Association, entitled "Comparative Construction and Maintenance Costs of Reinforced Concrete and Steel Bridges," bears directly on this question, and will be of great value to anyone working along the lines of concrete bridge building. In this paper Mr. Goodrich says:

At the quarterly meeting of the Association of American Portland Cement Manufacturers, held in Philadelphia, April 10, 1907, Mr. George S. Webster discussed the subject of "Concrete Bridges." In it he described briefly the Walnut Lane Bridge in Philadelphia. In answer to an inquiry, he said:

"The contract price for the bridge was $262,000. A steel bridge would probably cost less in this location; a

stone bridge, approximately 50 per cent more. The additional cost of this bridge over one of steel is due to the cost of centering. As the bridge is located in Fairmount Park and over the picturesque Wissahickon creek, a steel bridge would be inappropriate with the surroundings."

In this case it is to be observed that no real competition took place between those advocating concrete and those who exploit steel bridges. A decision was reached requiring the construction of concrete, and the first cost was of rather secondary consideration. And that has come to be the general attitude of those associated with the selection of types of bridges for given sites. At that time alternate bids were often asked for steel bridges and also for concrete arch construction. Among many such cases, the following may be cited, wherein the reinforced concrete design carried an estimated cheaper first cost:

(a) A seven-span bridge of concrete at Waterloo, Iowa, cost $54,000, or $1.80 per sq. ft., while the lowest bid for a plate-girder construction was higher.

(b) A seven-span bridge of concrete at Dayton, Ohio, cost $123,170. Eight bids were received for a steel plate-girder design, and seven on the concrete-steel design. The latter were about $10,000 the lowest.

(c) A 120-foot span concrete bridge at Lansing, Mich., cost $31,000, while the lowest of the three steel bids was $35,000. . . .

(e) A cheap but substantial highway bridge in Wabash county, Indiana, which was guaranteed flood-proof, cost $573 in competition with steel bridges and plain concrete culverts of same span and roadway, the lowest bid on steel being $665 and on plain concrete $943. . . .

(g) At Yorktown, Ind., was erected a 95-ft. span highway bridge for about $100 less than the lowest bid for a steel truss bridge of the same span.

On the other hand steel often is of less first cost than concrete: . . .

(b) At Stockbridge a small foot bridge over the Housatonic, if built of iron, was estimated to cost $1,475, while the concrete one actually erected cost more than that figure, because of bad foundations.

(c) The competitive plans prepared for the memorial bridge over the Potomac, for the Chief Engineer of the Army, included several different designs in concrete. It is said that a steel structure for the same site would have cost about 33 per cent less than that of the winning design in reinforced concrete.

(d) In the competition for a bridge at Plainwell, Mich., twenty-three proposals were submitted for different types of steel bridges, varying in price from $14,000 to $26,000, all the leading builders in the country being represented. For concrete-steel construction six bids were received, ranging from $16,000 to $27,000. The board favored a concrete bridge, but the only bid within the appropriation ($20,000) was rejected on account of faulty design. At an adjourned letting, three bids were received for concrete-steel, varying from $19,900 to $20,500.

Some other comparisons in first cost may also be instructive:

(a) For a bridge over the Neutra at Neuhansel, in Hungary, a concrete bridge consisting of six spans, each 55.8 ft. in the clear, cost $13,700, while a wooden one of twelve spans was estimated to cost $12,000.

(b) The concrete arch over Park avenue, in Eden Park, Cincinnati, cost $7,130, while a stone structure was estimated at $12,000.

(c) At Belleville, Ill., for a bridge over Richmond creek, plans were prepared for bridges of iron, stone, brick, and concrete. Bids were received on the last two named only, and ranged between $11,259 and $12,830 for a brick arch, and between $10,433 and $12,110 for concrete.

(d) At Indianapolis, the lowest price received for building two Melan bridges was $105,340, the lowest price for stone bridges being $140,996. Steel bridges, although somewhat lower in cost than the concrete ones, were rejected on account of their inferior beauty and their temporary character.

In an interview with Mr. Edwin Thatcher, the Nestor of concrete bridge builders of the United States, he stated that concrete could almost always compete with steel for highway structures whenever the floor in each case was to be paved like the street surface. When, however, a plank floor was allowed in the case of the steel structures, concrete could not usually compete successfully, simply on the basis of first cost. . . .

Mr. George P. Carver, in his handbook on Reinforced Concrete, gives detailed estimates of concrete arch bridges of 50, 75, and 100-ft. span, 28 ft. wide, from which he has prepared a curve of costs to be used in roughly estimating such structures for interurban railroad use:

The estimates are as follows:

SPAN, 50 FT.; WIDTH, 28 FT.

Steel, 27,700 lbs., at 2½ cents	$ 692.50
Steel placing, 27,700 lbs., at 1 cent	277.00
Form work at $1 per cu. yd	370.00
Cement, 481 bbls., at $2	962.00
Sand, 185 cu. yds., at $1	185.00
Stone, 370 cu. yds., at $2	740.00
Mixing and placing 370 cu. yds. at $1.50	555.00
	$ 3,781.50
Incidentals, add 15 per cent	567.22
	$ 4,348.72
Profit, add 10 per cent	434.87
	$ 4,783.59

TABLE IV
Dimensions and Costs of Concrete Arch Bridges

Place	Over	Total Length Bridge	Arch Spans	Width	Rise of Arch	Total Cost	Cost Per Sq. Ft.	Date Erected
Pine Road, Phila.	Pennypack Creek		2a 25'4¾"	34'3¾"	6'6"	$ 8,662	$ 4.94	1893
Neuhansel, Hungary	Neutra		6a 55'9½"	19'8"	3'8½"	13,700	2.00	1893
Richmond Av., Syracuse	Harbor Brook		12'0"	49'0"	2'6"	2,000	3.40	1894
Eden Park, Cincinnati	Park Ave.		70'0"	32'0"	10'0"	7,130	3.15	1895
Stockbridge	Housatonic		100'0"	7'6"	10'0"	1 475	2.00	1895
Belleville, Ill	Richmond Creek		40'0"	52'0"	7'0"	10,500	3.90	1895
Topeka	Kansas River	693'0"	5a 125'0" 2a 110'0" 2a 97'6"	40'0"		125,000	4.50	1896
Green and Goat Islands	Niagara	371'0" 198'0"	2a 103'6" 1a 110'0" 2a 50'6" 1a 55'0"	40'0"		102,070	4.50	1900
Indianapolis	Fall Creek		6a 74'0"	65'0"	9'6"	105,340	3.70	1900
Washington	Rock Creek		80'0"	27'0"	15'0"	17,500	8.10	1901
Wabash Co., Ind.			25'0"	16'0"		573	1.45	1902
Forest Park, St. Louis			45'0"	45'0"		10 600	5.20	1902
I. C. R. R.	Big Muddy River	483'0"	3a 140'0"	34'2"	30'0"	125 000	7.60	1901-3
Plainwell, Mich.	Kalamazoo River	446'0"	7a 54'0"	25'0"	8'0"	19 900	1.80	1903
Saley St., Brooklyn	Prospect Ave	125'0"	85'0"	60'0"		21,800	4.30	19—
Munich	Grunwald	720'0"	2a 230'0"	30'0"	42'0"	65,000	3.10	1904
Connecticut Av., Washington		1,341'0"	2a 82'0" 5a 150'0"	52'0"	41'0" 75'0"	850,000	12.20	1905
16th St., Washington	Piney Branch	272'0"	125'0"	25'0"	39'0"	42,721	6.25	1905
Dayton	Great Miami	588'0"	69'0"-88'0"	16'0"		123 170	3.70	1904
Park Ave., Newark	Branch Brook Pk.	243'7"	132'0"	74'0"	10'2"	84 000	4.70	1905
Connington, Viaduct		600'0"	10a 50'0"	16'0"	16'0"	52 200	5.43	1903
Greensburg, Ind.	Clifty Creek		80'0"	16'0"	12'0"	2,695	2.10	.....
Wayne St., Peru	Wabash River	500'0"	6a 75' to 100	30'0"	15'0"	36,900	2.46	.....
Wabash Ind.	Charley Creek		2a 75'0"	30'0"	18'0"	7,000	1.56	.....
Muncie, Ind.			38'0"	16'0"	7.6"	640	1.21	.....
Bangor, Me		90'0"	46'7¾" 38'2"	40'0"	8'7" 7'6"	6,500	1.80	.....
Sandy Hill		1,025'0"	15a 60'0"	35'8"		72 000	2.00	.....
Walnut Lane, Phila.		585'0"	233'0"	60'0"		262 000	7.50	.....
Maryborough, Queensland		613'0"	a 80'0"	22'8"	4'0"	75,000	5.40	.....
Lansing, Mich.	Grand River		120'0"	52'10"	23'0"	31,000	4.90	.....

REINFORCED CONCRETE GRAND STAND.

STEEL LAGGING FORMS AND STEEL LAGGING IN PLACE IN 12 BY 13-FT. BORE CONNECTING ILLINOIS TUNNEL COMPANY'S SYSTEM WITH THE CHICAGO POSTOFFICE.

STEEL COFFERDAM USED IN CONSTRUCTION OF BRIDGE OVER CHICAGO RIVER AT RANDOLPH STREET, CHICAGO.

Interlocking steel sheeting. Right-angle turn at corners made by riveting I-beams together.

Courtesy of Calvin W. Hendrick, Chief Engineer, Sewerage Commission, Baltimore, Md.

COMPLETED SECTION OF LARGE REINFORCED CONCRETE OUTFALL SEWER, BALTIMORE, MD.

Inside dimensions, 11 ft. by 12 ft. 3 in.

SPAN, 75 FT.; WIDTH, 28 FT.

Steel, 38,000 lbs., at 2½ cents	$ 970.00
Placing steel, 38,800 lbs., at 1 cent	388.00
Form work at $1 per cu. yd	740.00
Cement, 962 bbls., at $2	1,924.00
Sand, 370 cu. yds., at $1	370.00
Stone, 740 cu. yds., at $2	1,480.00
Mixing and placing 370 cu. yds. at $1.50	555.00
	$ 6,982.00
Incidentals, add 15 per cent	1,047.30
	$ 8,029.30
Profit, add 10 per cent	802.93
	$ 8,832.23

SPAN, 100 FT.; WIDTH, 28 FT.

Steel, 38,800 lbs., at 2½ cents	$ 970.00
Placing steel, 55,650 lbs., at 1 cent	556.50
Form work at $1 per cu. yd	1,008.00
Cement, 1,310 bbls., at $2	2,620.00
Sand, 504 cu. yds., at $1	504.00
Stone, 1,008 cu. yds., at $2	2,016.00
Mixing and placing 1,008 cu. yds., at $1.50	1,512.00
	$ 9,607.75
Incidentals, add 15 per cent	1,441.16
	$11,048.91
Profit, add 10 per cent	1,104.89
	$12,153.80

Table IV gives some of the dimensions and costs of a number of arches. In the case of single arch spans, the cost per square foot is computed from face to face of abutments and out to out of railings.

Continental European practice is well described by Professor Morsch in "Eisenbetonbau":

"In the early stages of railroad construction culverts roofed with natural stone were extensively employed.

With the advent of concrete and of cement pipe, arched conduits, easily constructed in concrete, or, for smaller openings, concrete pipes were substituted. With the introduction of reinforced concrete, however, slab culverts again became useful. Since it is possible with the aid of reinforcement to make the concrete slab resist any bending stress, the span of the slab on the clear way through these culverts can be increased to about 21 ft., so that their field of usefulness has been greatly extended. The span might be still further increased, but beyond about 16 ft., T-beams are cheaper than simple slabs. . . . The usual arrangement is (then) to span the opening with several similar parallel girders and lay a floor-slab between them. . . . T-beam bridges of this type, of spans up to 52 ft., are entirely practicable and in most cases cheaper than steel bridges. Special instances exist of 66-ft. spans. . . . With wider spans, the girders become rather heavy, so that T-beam bridges possess little superiority over steel ones. . . .

"An important advantage of such reinforced concrete bridges over railways is that they are not affected by the gases from the locomotives, which, in the case of busy stretches of track and where difficult of access, cause active corrosion and high maintenance charges for steel structures. . . . If the length of a horizontal reinforced concrete bridge is greater than 43 to 66 ft., intermediate supports must be provided.

"In straight girder bridges of greater lengths, an expansion joint must be provided about every fourth opening. . . .

"In arched bridges, reinforced concrete can be employed either for the arch alone or the superstructure, including the roadway, or in all structural parts. . . .

"In medium spans of 130 to 165 ft., the employment of reinforced concrete as the arch material is less frequent, since in this case, provided a proper profile has been employed, no tensile stresses occur, because of the

large dead load. On the other hand, reinforced concrete is better adapted for long spans. If the safe compressive stress in the arch is not to be exceeded, it is necessary to limit the weight of the superstructure, and this can be done by a suitable employment of reinforced concrete. In this way the dead load stresses will be greatly reduced, but the small edge stress may decrease to zero or change to tension under unfavorable live loads, so that the reinforcement is again necessary.

"In consequence, where it is desired in small and medium spans that no tensile stresses shall exist, or, in other words, where only mass concrete work is employed, the superstructure cannot be kept too light. A light superstructure is then justifiable only when demanded for architectural reasons, or when it is necessary to impose as little weight as possible on the foundations. . . .

"The arches can be constructed as restrained, or as three-hinged, by using suitable material. . . ."

Prof. Morsch finally remarks that arched bridges with a proper arrangement of reinforced concrete and of large span, can compete successfully with steel construction.

The governing bodies of municipalities, counties, companies, etc., are altogether too prone to accept the lowest bid in a competition, irrespective of the qualifications of the bidder. Many inexperienced men have submitted figures on work which they were unable to compass, when put to the actual test, often losing heavily, but being compelled for business reasons to shoulder the loss and say nothing. In other and rarer cases, the work has suffered to a dangerous degree, and the municipality or other body for which the bridge was erected has lost much more through costs of repairs, than the difference between the lowest actual and the lowest responsible bid. Such bodies will usually save money in the long run by retaining the services of an expert concrete engineer, who will either prepare a single design upon which all bidders can base their figures, or prepare specifications calling for

detailed designs accompanying each bid, with the privilege retained of accepting any bid which is considered as best meeting the requirements of the case. A waiver should also be exacted of each bidder, concerning any claim whatsoever for himself or any other if his bid is not accepted.

All the costs contained in Table IV are first costs, or the initial expenditure, which is almost invariably financed by an issue of bonds by the municipality, township, or corporation undertaking the erection of the structure. These bonds usually carry about four per cent interest, and run for a period of from twenty to fifty years. provision for their retirement being made by the establishment of a sinking fund in which is placed a small yearly percentage raised by taxation or derived from income. The gross amount of these two annual obligations thus usually amounts to between six and ten per cent of the cost of the structure. This condition is the same, irrespective of its type, the only point being the reduction of this yearly expenditure to a minimum by cutting down the first cost as much as possible, and extending the life of the bonds as much as advisable so as to reduce the annual amortization charge. Obviously, the bond period should not extend over a greater period than the life of the structure.

The question then immediately arises as to the probable relative and actual lives of various types of bridges. Stone arch bridges have been in existence from the times of antiquity, but the advocates of steel structures will say "they were not built of concrete." In the south of France is a concrete arch bridge known as the Pont du Gard, which was erected in the year 56 B. C. The concrete in this was not composed of crushed stone or other small aggregate of the variety now employed in concrete bridge work, but was of the old style, consisting of alternate layers of large and small stones, gravel, etc., and of cementitious materials. Vitruvius describes the materials

and methods in use before the Christian era, and other writers like Alberti in 1485 and Palladio in 1570 accurately describe the method which "the ancients" (as they call them) employed, "of using boards laid on edge and filling the space between with cement and all sorts of small and large stones mingled together." It is very improbable that the Pont du Gard would have withstood the rigors of climate of the Northern United States, but its actual state of preservation, as well as that of many other specimens of ancient concrete work, proves that if modern work is honestly executed, it will many times outlast any reasonable bond period, so that a very small yearly sinking fund per cent is all that is required for properly designed and erected concrete work. . . .

To steel or wooden structures, on the other hand, only a relatively short life can be assigned at best. Wood will be dismissed without further comment, except to remark that, in some parts of the West where wood is exceedingly cheap, and where steel and cement can be obtained only after being transported very long distances, so that their costs are very high (from the heavy freight rates made necessary), it may be possible that wooden structures involve the smallest yearly charge, in spite of their very short life, even when treated with creosote or other preservatives.

Turning to steel then as the only real competitor of concrete, a remark ascribed to the late George S. Morison is often repeated, that,

"Steel bridges are built to last fifty years, but they do usually last hardly half that time."

This condition is due to insufficient or entire absence of maintenance. The writer has been told of one highway bridge in Wisconsin which had to be replaced after only eight years of service. Of course this is an exceptional case. Steel bridges over railroad tracks where locomotive gases can produce their full destructive effect,

have been known to last just about the same period. Morsch cites an example of a girder erected in 1886, and found with its web entirely eaten away at many points, in 1907. . . .

Where highway bridges are properly maintained, even when subjected to the action of locomotive gases, they have been known to last much nearer the theoretical limit assigned them by Mr. Morison. . . . With careful inspection and maintenance there is really no reason why a well-constructed steel bridge should not last indefinitely, and such structures as Brooklyn Bridge (built in 1884), or the Niagara arches, may be expected to see many generations.

In the "Technograph" of the University of Illinois, for 1893, Mr. Albert F. Robinson, Engineer of Bridges and Buildings of the C., R. I. & P. Ry., states the principle that the life of steel railroad bridges is only fifteen years, because they must all be rebuilt to accommodate heavier traffic at intervals of about that length.

A conservative deduction from the above-mentioned and many other observations, would lead to the conclusion that ordinary highway bridges should not be assigned an average life exceeding twenty years at most; and fifteen would be a really better period to which to limit the life of steel highway bridge bonds. Railroad bridges usually receive better care, and their life may be considered as somewhat longer, except that from time to time they must be strengthened in order to make them safe for increased loads.

Mr. Robinson, in the paper cited above, presents estimates of the costs of strengthening single-track structures of different lengths, assumed to have been erected about 1882 in accordance with the standard specifications of the Erie Railroad, and so rebuilt as to conform to the standard specifications of the Lehigh Valley Railroad. In condensed form they are as follows:

Length in Feet.	Cost in 1882.	Cost of Strengthening in 1897.	Per Cent.
40	$ 901.10	$ 377.27	41.4
50	1,344.20	580.50	43.0
60	1,816.20	713.50	39.25
80	3,036.20	1,408.15	46.0
100	4,539.00	1,925.50	42.0
120	6,018.00	2,857.30	47.0
140	7,792.28	3,573.90	46.0
160	9,929.70	4,388.35	44.0
180	11,679.00	5,158.50	44.0

These figures reveal the average percentage of cost of renewal to be 43.6. This is in addition to the regular maintenance costs, and is equivalent to about 3 per cent per annum, corresponding to a life of about thirty-five years for the original structure, computed on this purely theoretical basis.

In discussing this subject it is very difficult to separate the annual depreciation from the maintenance costs. Lumping all such items together, the New York Central assumes 5 per cent per annum as the amount on which to base all maintenance and depreciation charges, when contracting with municipalities concerning railroad and highway crossing structures. Since this figure is to cover all charges of whatsoever kind, it is necessary to assign somewhat more than this figure, or about thirty years, as the assumed life of the bridge, and thus a somewhat arbitrary but fairly satisfactory rate of depreciation can be assumed for all steel bridges. On this basis, at least 5 per cent should always be assumed as the yearly amortization rate for such structures, against not to exceed 2 per cent, corresponding with a bond period of fifty years, for concrete ones, irrespective of first cost.

Inspection and Maintenance. Turning now to the subject of maintenance, pure and simple, nothing has yet been written better than the Preliminary Report of the Committee on Iron and Steel Structures of the American Railway Engineering and Maintenance of Way Association:

"The maintenance of a metal bridge consists in the

prevention of deterioration by rust and wear, the repairing of all damage resulting from internal or external causes, and the necessary strengthening of the structure if called upon to carry loads heavier than those for which it was designed.

"To attain these ends, the structure must be kept free from rust by proper cleaning and painting; motion between the various parts must be reduced to a minimum; expansion joints must be kept working freely; all defects and injuries must be promptly discovered and repaired; and its capacity determined as accurately as possible.

"The purpose of an inspection is to ascertain the condition and safety of the structure, and to determine the amount and rate of deterioration and the necessity for repairs or renewal. Ordinarily a thorough annual inspection made by a competent inspector will suffice for most cases where the bridge is properly constructed and is not overloaded. On the other hand, nothing short of a daily inspection will be sufficient to discover with sufficient promptness the damage caused by an accidental blow.

"Between these two extremes there are many reasons for making inspections of more or less thoroughness and frequency.

"The following scheme for inspection seems to be an average of practice. It is applicable to either the divisional or departmental system of maintenance:

"(1) By track men daily in connection with the inspection of the track, to note especially whether the structure has suffered any damage from drift, high water, slides, or objects falling from cars, and any movement of the substructure.

"(2) Monthly by a member of a bridge gang reporting through the foreman to the Supervisor of Bridges and Buildings, to ascertain condition and safety of structure and repairs necessary.

"(3) Annually by an inspector, to obtain a detailed

report of the condition of the structure for office record, and to determine the amount of deterioration, safety, and necessity for repairs or renewals.

"(4) Annually by the authorities having charge of of the structure, to determine the necessity for extensive repairs or reinforcement or renewals.

"In addition to the foregoing, special examination should be made as occasion may require as follows:

"(a) Of structures that are strained high or show signs of distress under traffic.

"(b) Of substructures showing signs of movement, until it has been ascertained that a state of stable equilibrium has been reached, or until movement becomes so great that rebuilding is necessary.

"(c) After heavy floods, for evidence of damage to superstructure by drift, and to substructure by scour.

"(d) By engineering department whenever a structure is reported as requiring repairs or renewals."

The items which are to be noted by the inspector, as required by the Oregon Short Line Railroad, are as follows:

1. Class of structure.
2. Length.
3. Opening of spans.
4. Height of base of rail.
5. Approaches.
6. Ties.
7. Rails.
8. Spike.
9. Guard-rails.
10. Stringers, attachments.
11. Corbels.
12. Caps, sills, timber walls.
13. Posts or piles.
14. Sway braces.
15. Waterway.
16. Culvert pipe.
17. Box culverts.
18. Paving.
19. Bench and end walls.
20. Ring or covering stone.
21. Piers and abutments.
22. Pedestal blocks.
23. Bed-plates.
24. Anchor-bolts.
25. Line camber.
26. Tension members.
27. Compression members.
28. Floor beams, attachments.
29. Lateral connections.

30. Hangers.
31. Long suspenders.
32. Loose pins or nuts.
33. Loose rivets.
34. Drain-holes.
35. Vibration.
36. Deflection.
37. Painting.
38. Wall-plates.
39. Bolsters.
40. Angle-blocks.
41. Bottom chord joints.
42. Chord bolts.
43. Clamps and packing.
44. Gib-plates.
45. Covering.
46. Water barrels.
47. Ladders.

A somewhat similar list of items concerning concrete or stone arch bridges is as follows:

1. Class of structures.
2. Length.
3. Opening or spans.
4. Height to base of rail.
5. Approaches.
6. Ties.
7. Rails.
8. Spikes.
9. Guard-rails.
10. Waterway.
11. Paving.
12. Soffets.
13. Spandrels.
14. Abutments.
15. Wing walls.
16. Piers.
17. Parapets.
18. Drain holes.
19. Expansion joints.
20. Vibration and deflection.

The points to be noted are almost entirely cracks—their location, width, length, depth, and water-bearing qualities. Their location will determine to a certain extent whether they are due to settlement or spreading of abutments, to setting shrinkage, changes of temperature, or overloading. Their change of size with variation in load, humidity, temperature, etc., will afford further information, especially as to their cause and cure. The amount of water coming through them, and its quality, are of importance in determining the dangerousness of their existence from another point of view.

In properly reinforced concrete, failure is sure to be very gradual, so that there is less chance for accident

than in some other types of structure; nevertheless, it is wise to inspect them just as frequently as is done on other varieties of bridges. Their foundations should be given especial care in original design, in construction, and in periodical inspection after completion, because there is almost invariably a smaller waterway left in the design of arch bridges, than in the case of the vertical abutments for a steel bridge. Worse scouring, especially in time of flood, may thus be produced, and inspectors should note all phenomena along this line. On the whole, therefore, no saving can be made in the costs of inspection by the erection of concrete structures in place of steel, and hence this small but important item can be ignored in making a comparison.

One of the best-known reinforced concrete construction companies gives the following reasons for the choice of concrete structures in place of steel:

STEEL BRIDGE

Labor, steel, material—all come from out of town.

When built, the bridge is unsightly; costly to maintain in roadway and paint; constantly in need of inspection; short-lived; with wooden floor in danger of burning; subject to rust in hidden parts; noisy under traffic.

In general use only because up to the introduction of the reinforced concrete arch it was the only fairly durable low-priced bridge.

REINFORCED CONCRETE BRIDGE

Most of the carpenter and other labor is hired in the town.

Gravel, sand, stone, cement, lumber, teaming, board—money for all these goes into the business of the town.

When the bridge is built, it increases in strength as it grows older; it is the most graceful bridge made; there is no maintenance expense; it is quiet under traffic.

When maintenance of a steel bridge is considered, a reinforced concrete bridge shows economy of investment.

It is the last claim in which the present interest centers and by the foregoing presentation, the only points now left open for comparison are costs of roadway renewal and of re-painting. The former is a most difficult matter for determination since a concrete structure will always carry the regular railroad ballast and track, or the highway or street surfacing, which has to be maintained only to the same extent as the adjoining thoroughfare. It has already been stated that concrete cannot usually compete with steel highway bridges (as to first cost), when the latter are to be designed with plank

TABLE V

Cost of Bridge Steel Work and Floors

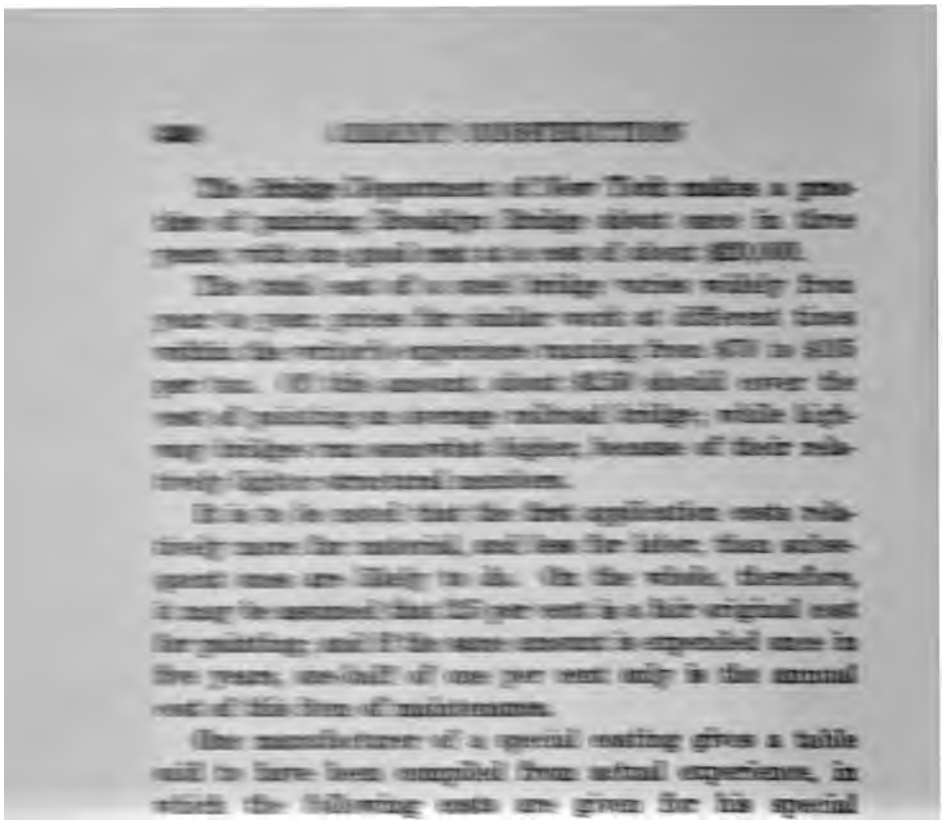
Span	Type	Cost Per Foot of Span			Per Cent Cost of Renewal of Timber Work Per Year
		Steel	Floor System	Total	
45	Pl. girder	$25.00	$ 3.00	$28.00	1.1
60	Pl. girder	30.00	3.00	33.00	0.9
85	Pl. girder	39.00	3.00	42.00	0.7
100	Pony lattice	38.00	6.00	44.00	0 7
100	Lattice	29.00	10.00	39.00	0.8
125	Lattice	35.00	10.00	45.00	0.7
150	Pin	36.00	12.00	48.00	0.6
175	Pin	41.00	12.00	53.00	0.6
200	Pin	46.00	12.00	58.00	0.5
250	Pin	60.00	12.00	72.00	0.4

flooring. The life of this material is extremely variable, depending almost entirely on the density of traffic. On Brooklyn Bridge the 2½-inch spruce plank of the wearing surface must be replaced about every four months, while the writer has known of country highway bridges in which the flooring rotted away so as to need renewal before the traffic had produced enough wear to necessitate relaying. Between these two extremes, the conditions are so wide as to make this item too indefinite to be entertained except in cases or locations where the wear and cost of renewal are known. In such an in-

stance it is only necessary to estimate the yearly expense for renewal, and compute from it the percentage of the total cost of the structure. As an example, assume a bridge 100 ft. long and 30 ft. wide, of which the planking has to be renewed once a year. Assume a 3-in. yellow pine wearing surface, which costs, including tearing up, spikes, labor, material, and supervision, $40 a thousand. This item then aggregates $30\times100\times3\div1000\times40=\$360$. If the initial total cost of the structure were $10,000, the yearly percentage cost of roadway renewal would be slightly less than four. This figure is known to be very modest, and when it (representing a yearly cost of 12 cents per square foot in this instance) is compared with $1.35 per square foot, which is about the yearly cost of renewal of the planking of the Brooklyn Bridge, this point is made all the clearer.

The floors of railroad bridges (unless constructed with buckle plates or similar material, on which the regular ballast roadbed is carried), are largely of timber, which has a relatively short life. In general it may be estimated that the wooden portion of such a floor will last about ten years in the northern part of the United States, decreasing to about six in the Southern States. The cost of a floor is almost purely a function of the length of the bridge alone, so that it is impossible to assign to it a percentage value. A rough estimating figure of $3 per ft. per track is sometimes given for the timber work. Table V gives some estimated costs of steel work and railroad bridge floors for different spans, for the sake of comparison.

The painting of a steel structure is a great question. There are several hundred "best paints" on the market, some of which are good, and some of which will hardly last until the paint salesman can collect his bill. The best paints obtainable will last about six years, after which period a new painting is necessary for good maintenance.



[illegible] Department of New York makes a practice of painting Bowstring Bridge about once in five years, with an annual cost of about [illegible].

The total cost of a steel bridge varies widely from year to year, since the amount of work at different times within the entire appropriation ranging from $70 to $115 per ton. Of this amount, about $[illegible] should cover the cost of painting an average railroad bridge, while highway bridges can usually be painted for [illegible] because of their relatively lighter structural members.

It is to be noted that the first application costs relatively more for material, and less for labor, than subsequent ones are likely to do. On the whole, therefore, it may be assumed that 50 per cent is a fair original cost for painting, and if the same amount is expended once in five years, one-half of one per cent only is the annual cost of this item of maintenance.

One manufacturer of a special coating gives a table said to have been compiled from actual experience, in which the following costs are given for his special material:

Kind of Bridge	Days of Work Required for 100 Tons of Steel	Per Cent per Annum per Ton of Steel
Highway	[illegible]	[illegible]
Highway	[illegible]	[illegible]
Highway	[illegible]	[illegible]
Railway	[illegible]	[illegible]

It is claimed for this special material that a new application need be applied only once in ten years. This makes the percentage cost of paint per annum on the basis of $65 per ton of steel as follows:

Kind of Bridge	Span	Per Cent per Annum
Highway	[illegible]	[illegible]
Highway	[illegible]	1.41
Highway	[illegible]	0.70
Railway	[illegible]	0.47

Collecting together now the several points discussed, a recapitulation will be as follows:

Yearly cost of inspection should be about equal, for the two classes of structures.

Depreciation and consequent sinking fund requirement for steel, at least 5 per cent; for concrete, not to exceed 2 per cent.

Cost of maintenance of timber, if used:

For steel highway structure, about 4 per cent;

For steel railway structure, about 1 per cent.

Cost of maintenance of regular pavement or earth road:

Surface for concrete structure, less than 1 per cent;

Of regular ballasted railway track less than 1 per cent.

Cost of painting:

Steel railway structure, less than 1 per cent.

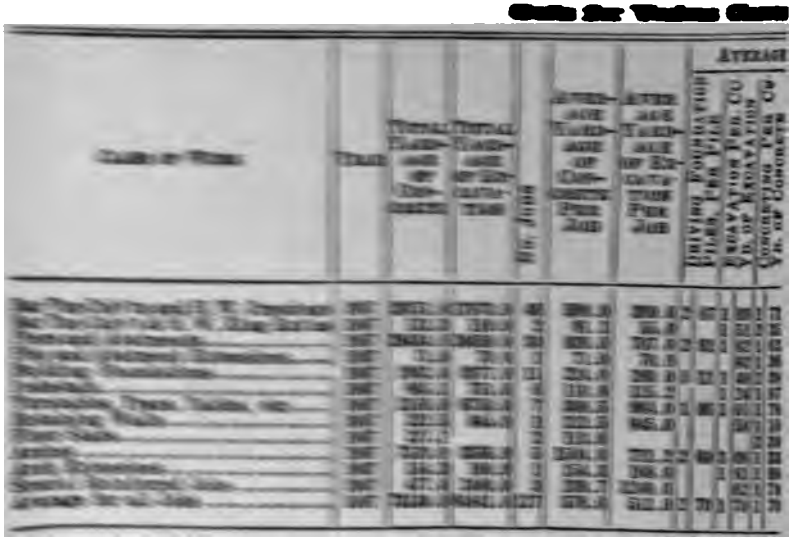
Steel highway structure, less than 2 per cent.

Total maintenance costs, aside from interest on first cost, for steel structure, from 7 to 11 per cent, depending on character of bridge and kind of flooring; for concrete structure, not to exceed 3 per cent.

Excess of steel over concrete, from 4 to 8 per cent.

This is a rough average percentage figure, therefore, which a company or community, should allow in the first-cost figure of a concrete bridge structure over the total cost of a steel structure for foundations and superstructure combined, in a true competition between the two classes of bridges. Of course, the interest charge is to be added in each case. In other words, 3 per cent of the cost of the concrete structure should be compared with 7 to 11 per cent of the cost of a competing steel structure, and that type should be selected which will give the lower result.

Or, as a special example, if the lowest responsible bid for a concrete arch is $12,000, the yearly cost to the community will probably be 4 per cent (assumed interest



charge, plus 1 per cent for depreciation and maintenance. Since the yearly costs for a steel structure will amount to from 11 to 12 per cent with 4 per cent assumed as above for interest for the steel superstructure and slightly less for the substructure, unless the span length exceeds 200 feet, the cost will be greater than those of a concrete structure.

In order to determine the most economical type of structures for short-span railway bridges, the costs of four different designs were computed for span lengths of from 10 feet to 35 feet. The four types of structures which were estimated are as follows:

A—I beam span with standard open wooden floor.
B-1—I beams imbedded in concrete and ballast floor.

TABLE VI—(Concluded)

of Concrete Bridge Work

Cost of Labor							Average Amount of Material																Average Total Cost of Materials Per Cu. Yd. Concrete Excl. of Special Items.		Average Total Cost of Concrete Per Cu. Yard. Excl. of Fdn. Piles and Special Items	
Concrete Forms							Ft. B. M. of Lumber Used								Sacks Cement Per Cu. Yd. Concrete											
Per Cu. Yard Neat Work		Per Sq. Yard Form Surface		Total Per Cu. Yard Concrete Excl. of Exc. Fdn. Piles, Moving and Spec. Items		Total Per Cu. Yard of Concrete Excl. of Fdn. Piles and Special Items	Cofferdam Per Cu. Yd. of Footing		Concrete Forms Per Cu. Yd. Neat Work		Concrete Forms Per Sq. Yd. Form Surface		Crushed Stone Per Cu. Yd of Concrete		Sand or Gravel Per Cu. Yd. of Concrete		In Footing		In Neat Work		In Cover					
1	63	42		2 11	3	58	14	3	22	0	14	7	98		51	4	34	4	58	5	16	3	12	6	70
	34	46		3 04	5	68	9	0	2	5		9	91		84	3	63	4	82	5	88	2	79	8	47
	65	53		2 06	3	78	38	5	17	7	14	5	82		57	4	38	4	64			3	14	6	92
1	66	39		1 80	3	47	40	8	8	9	5	3	59		18	3	56	4	53			2	78	6	25
	46	36		3 48	5	28			36	8	9	2	90		73	5	54	5	32			3	75	9	03
	71	33		2 31	3	87	7	1	25	0	11	5	86		59	4	16	4	50			2	87	6	74
	87	35		2 24	5	55	33	2	20	4	8	3	90		61	4	62	4	58			3	29	8	84
	61	20		1 43	4	32			33	7	11	1	81		58	3	85	4	35			2	81	7	13
1	16	21		3 54	3	87			33	0	15	1	74		55					5	58	5	20	9	07
1	33	91		2 30	4	02	25	2	24	5	16	7	99		50	4	45	4	54	5	12	3	25	7	27
	86	49		2 03	4	69	19	4	24	0	13	6	86		44	4	40	5	40			3	30	7	99
5	20	95		4 03	7	57			105	0	19	2	76		61	6	02	6	16			4	33	11	90
	86	52		2 27	4	04	24	3	22	6	13	7	90		54	4	44	4	69	5	17	3	20	7	24

B-2—Concrete ballast floor supported on I beams.

C—Reinforced concrete slab with ballast floor.

The spans were figured for the total dead loads and a Cooper's E-50 live load. The unit allowed stresses in the steel beams were 8,000 lbs. per square inch for live load, and 16,000 lbs. per square inch for dead load. The allowed unit-stresses in the concrete slabs were 750 lbs. per square inch in the concrete, and 13,500 lbs. per square inch in the steel, for dead load; and 500 lbs. per square inch in the concrete, and 9,000 lbs. per square inch in the steel, for live load.

The steel beams were estimated to cost 2¾ cents per pound; the reinforcing steel, 3 cents per pound; the concrete, 35 cents per cubic foot,

[illegible] a cubic yard. The ballast and floor were estimated at $1.50 per linear foot, and the wooden floor at $3.00 per linear foot.

The costs for each of the four designs for the various spans were plotted as shown in Fig. 32. The spans are laid off on one axis; and the costs in dollars for the structure, exclusive of abutments, are laid off on the other axis. Fig. 32 shows also the cross-sections of the four types considered. An inspection of the curves will show the following:

1. The I-beam spans with the open wooden floor are the cheapest.

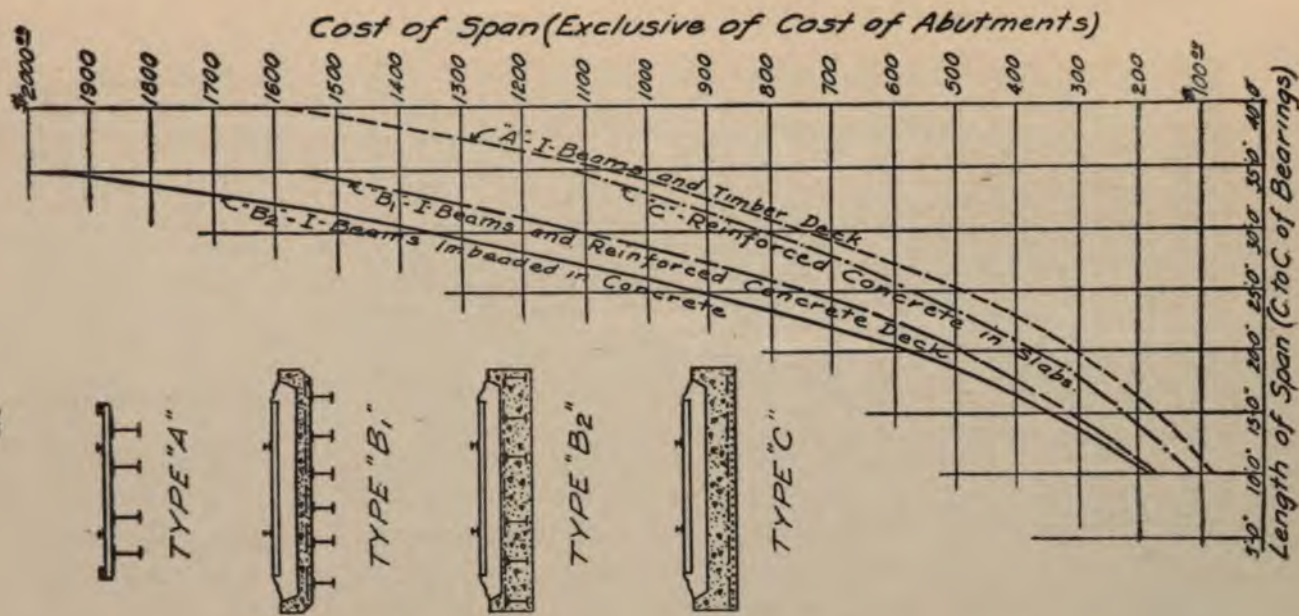
2. The reinforced concrete slabs are only slightly more expensive than the Type A spans, and cheaper than Types B-1 and B-2.

3. The Type B-2 spans, I-beams imbedded in concrete, are the most costly construction.

4. The difference in cost between the Type A and Type C spans does not increase as the span length increases.

5. The difference in cost between the Type C and Type B spans increases rapidly as the span length increases.

It will be noticed that a slight change in the relative costs of the steel and concrete in the various types will affect relative positions of the curves. The costs used are indicated to be average, and therefore the curves indicate the economy of the various types of spans in the average case. It is entirely possible, however, that under certain conditions the cost of con-



COOPER'S E50 LOADING

Estimated Cost

Structural Steel (I-Beams) $2\frac{3}{4}$¢ per lb
Reinforcing Steel (Bars) 3¢ per lb
} Concrete between I-Beams 35¢ per cu ft
Concrete in Slabs ("B1" & "C") 35¢ per cu ft

Fig. 82. Curves Showing Costs of Various Types of Short-Span Bridges.

erete may be so low that the Type **C** spans will be cheaper than the Type **A** spans.

The depth of a floor is usually an important consideration in short-span bridges, the shallowest floor allowing the greatest waterway. The concrete slabs compare favorably with the other spans in the depth of the floor. For example—for a 20-ft. span, the distance from the base of rail to the lowest point of the bridge is as follows: Type **A**, 2 ft. 6 in.; Types **B-1** and **B-2**, 3 ft. 9 in.; Type **C**, 3 ft. 7 in.

Many advantages of the ballast floor make the Type **A** construction less desirable than any of the other types. Amongst the ballast-floor bridges, Type **B-2** and Type **C** are to be preferred, because in these bridges the steel is not exposed to the action of the elements. Type **B-2** is not adapted for economical construction, as it does not utilize the concrete in carrying the load; and it is not to be recommended from an engineering standpoint, because it is questionable whether the load will be distributed equally over all the beams, and whether the concrete and steel will remain in contact.

In conclusion it may be said:

1. The Type **C** construction of reinforced concrete slabs has the lowest first cost of all the ballast-floor types, and is nearly as cheap as the open-floor steel span.

2. The reinforced concrete slabs take up as little headroom as the other ballast-floor types.

3. The reinforced concrete slabs can be built

in place, built alongside and moved in, or built at a distance and lifted in, while the other ballast-floor types cannot be so readily handled.

4. The reinforced concrete slabs are more permanent than the Type **B-1** spans with exposed beams, and afford better protection for the steel than in Type **B-2**, where it is questionable whether the concrete will remain in contact with the beams.

Table VI will be found of value as an actual record of the cost of various classes of concrete work as carried out during the year 1907 by a prominent contracting company for one of the large Eastern railway systems in the United States.

Concrete Retaining Walls

A retaining wall is a wall built for the purpose of supporting or holding back a bank of earth, rock, or other loose material. Such a wall is required wherever it is necessary to have an abrupt change in the level of the ground surface, and where it is not desirable, because of lack of space or for some other reason, to let the earth run out to its natural slope.

Because retaining walls are partially buried in the ground, and because they must endure indefinitely, they are constructed of masonry. Stone masonry walls depend on their weight to hold back the earth behind them and are seldom built nowadays, concrete being used instead. The use of reinforced concrete has made it possible to construct a number of economical types of wall which could not be built of plain concrete or stone.

The material behind a retaining wall is termed the **filling** or **back-fill.** This material has a tendency to slope out to an inclination which is less steep when fine, loose, or wet than when coarse and compact. The wall must be designed in such a way that it will resist this tendency of the back-fill to spread out; or, in other words, it must be designed so that it will not be pushed forward or overturned by the thrust or pressure of the back-fill. The thrust of the back-fill depends on the steepness of its

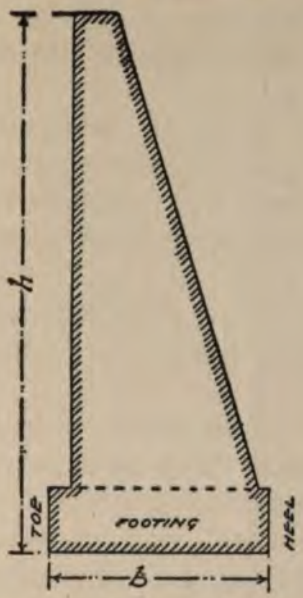


Fig. 83. Section of Gravity Retaining Wall.

Fig. 84. Retaining Wall of L-Section.

natural slope; and this, in turn, depends on the nature and condition of the material. As an approximation which has been assumed to represent average conditions, the horizontal thrust of earth filling at any depth is considered to be equal to one-third of the weight of the earth above this depth.

The tendency of retaining walls to slide forward is prevented by the depth of the foundations or by the use of piles. Walls are designed to resist overturning in two ways:

1. They are built of sufficient mass and weight.

2. They are constructed to utilize the weight of the earth resting on the back projection, or **heel**, of the wall.

The first-mentioned walls are known as **gravity walls.** Fig. 83 is a cross-section of a gravity wall. A safe rule for the design of such a wall is to make the width of the base **b** equal to $^4/_{10}$ of the height **h.**

The walls which utilize the weight of earth on the heel are of three distinct types, as shown in Figs. 84, 85, and 86.

Fig. 84 shows a wall of L section, with the position of the main reinforcement indicated.

Fig. 85 shows a wall of T section, the toe projections being about ½ of the heel projection.

Fig. 86 is a section of a **counterfort retaining wall.** In this type, which is the most economical for very high walls, the face and footing slabs span between the counterforts, which are tension members spaced at distances about equal to the width of the base of the wall. The width of the base of reinforced walls should be equal to about one-half of their height, instead of $^4/_{10}$ths, as in the case of solid gravity walls.

The preceding discussion of the design of retaining walls will indicate some of the **precautions to be taken in construction.** It is essential to secure a good foundation, deep enough to be safe from the action of frost and all danger of undermining, and firm enough to resist the forward thrust of the filling and the weight of the wall and superimposed earth. It is impera-

tive that the design shall be carried out, and that bars and joints shall be put where they are called for, and nowhere else. The back-fill should be properly placed and well drained.

Fig. 85. Retaining Wall of T-Section.

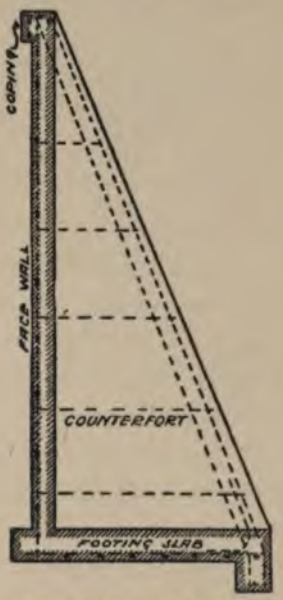


Fig. 86. Section of Counterfort Retaining Wall.

The form work used and the method of procedure adopted in building walls of various types, as illustrated and explained in the following pages, will familiarize the concrete worker with these structures in a better and more practical way than a theoretical discussion would.

At the Grand Central Station of the New York Central Railroad, the yards have been ex-

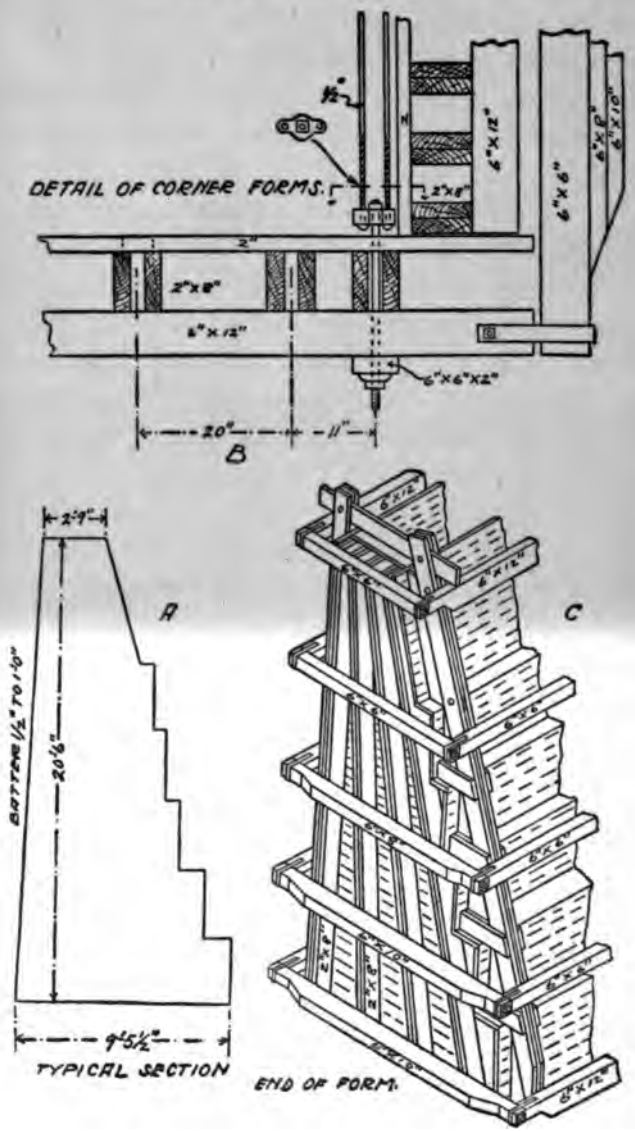


Fig. 87. Details of Retaining Wall Construction for New York Central Terminal, New York City.

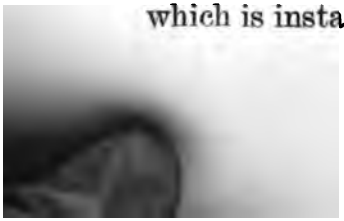
tended to a total area of about 43 acres, and are depressed to an average distance of about 20 feet below the adjacent streets, being enclosed by a massive concrete retaining wall (see Fig. 87, **A**, **B**, and **C**). The wall varies from about 11 to 21 ft. in height, and has a batter face with rear offsets 3 ft. high, as shown in the cross-section. It is made in full-height sections about 52 ft. long, with open vertical transverse expansion joints ⅛ in. thick between them. The moulds are built with horizontal 2-in. Virginia pine planks, ship-lapped ½ in., and laid ⅛ in. apart to allow for swelling. They are lined on the face with thin steel plates, and are secured by vertical spruce joists and removable horizontal yellow pine waling pieces, bolted on as indicated in the illustrations. The front and end sheeting is made in single large surfaces; but the rear sheeting is made in steps to correspond with the offsets, each one having a vertical and a horizontal part fitted to the framework like the tread and riser of a stair.

The waling pieces are fastened at the corners of the moulds by U-straps of 2-by-½-in. iron bolted to the longitudinal pieces, and projecting beyond their ends to engage the chamfered ends of the transverse strips. Intermediately, the longitudinal waling pieces are tied together through the mould by pairs of horizontal ½-in. rods $2^{3}/_{16}$ in. apart, with hemispherical upset heads at each end, engaging cast-iron sockets shown in the detail, which are placed just inside

the sheeting and are secured by short bolts with nuts engaging the castings. The opposite ends of the bolts have nuts taking bearing on the waling pieces. After the concrete has set, both nuts are unscrewed and the bolts removed, leaving the castings and the ½-in. rods permanently embedded in the concrete. The mould panels weigh from 2 to 3 tons each, and are handled by the 45-ft. boom of a locomotive crane.

The first mould was assembled with both ends closed by sheeting; and after it was stripped from the concrete, two moulds were used, and sections were built on both ends alternately, allowing one section to set while another was being built. These successive sections are made with moulds having front and rear sheeting and sheeting at the outer end only, the previously finished concrete closing the rear end of the mould where the front and side panels of sheeting overlap the faces of the concrete and are tightly clamped to it by the horizontal transverse rods. It takes a force of 20 men about 3 hours to strip a mould; and it takes 20 men about 7 hours to reassemble it and oil the inside ready to receive the next section of concrete. In large work of this sort, it would be possible to use 3 or more sets of moulds, and prosecute the wall building simultaneously at as many points.

Concrete is mixed and delivered to the moulds without hand work, by a movable plant, which is operated entirely by electricity and which is installed in a 13 by 16-ft. wooden tower



40 ft. high, which has eight double-flange wheels traveling on a track of 13 ft. 2 in. gauge about 5 ft. clear of the face of the wall. A standard-gauge track on the center line of the tower track receives material cars which run through the tower with a clearance of about 12 ft. horizontal and 14 ft. vertical, and which are unloaded by hand on a platform parallel to the track, where they are wheeled to a pair of 1-yd. steel automatic tilting buckets operated by a hoisting engine in the tower. The buckets run in vertical guides extending 16 ft. above the top of the tower, and deliver to two 10-yd. hopper-bottom storage bins about 7 ft. above the mixer floor, where 400 bags of cement are stored which are hoisted by whip lines operated by the capstan head of the hoisting engine.

The storage bin chutes are fitted at the bottom with horizontally pivoted troughs which close them when raised, and, when lowered, allow the sand and stone to be discharged to the measuring hopper where the cement is emptied, and all is delivered to the mixing machine while the revolution of the latter is uninterrupted. The mixer and hoisting engine are operated by independent motors, and the mixer delivers through an inclined chute to an end-dump tilting 1-yd. steel car which runs across the top of the mould on a 24-in. longitudinal track and distributes the 1:3:6 Portland cement concrete as required for the laborers, who place in it one-man stones and carefully spade the mortar

around the sides of the mould. The concrete is mixed wet and requires no ramming. Each mould holds about 250 cu. yds.; and the best record of filling it is 6¾ hours for 60 men, including those in the tower. The moulds are stripped the next morning after being filled; and con-

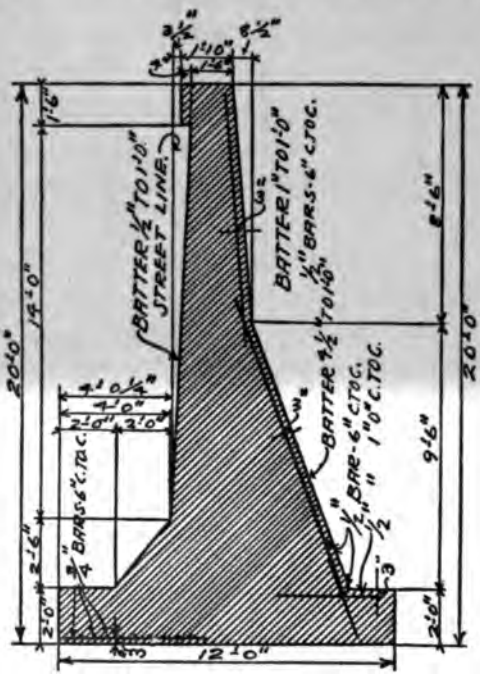


Fig. 88. Section of Partially Reinforced Concrete Retaining Wall.

creting for each mould is continuous until it is completed. The total number of men employed on the concreting and handling the moulds is about 75, and the largest record is 2,700 yds. of concrete in one month.

Fig. 88 is a cross-section of a concrete retain-

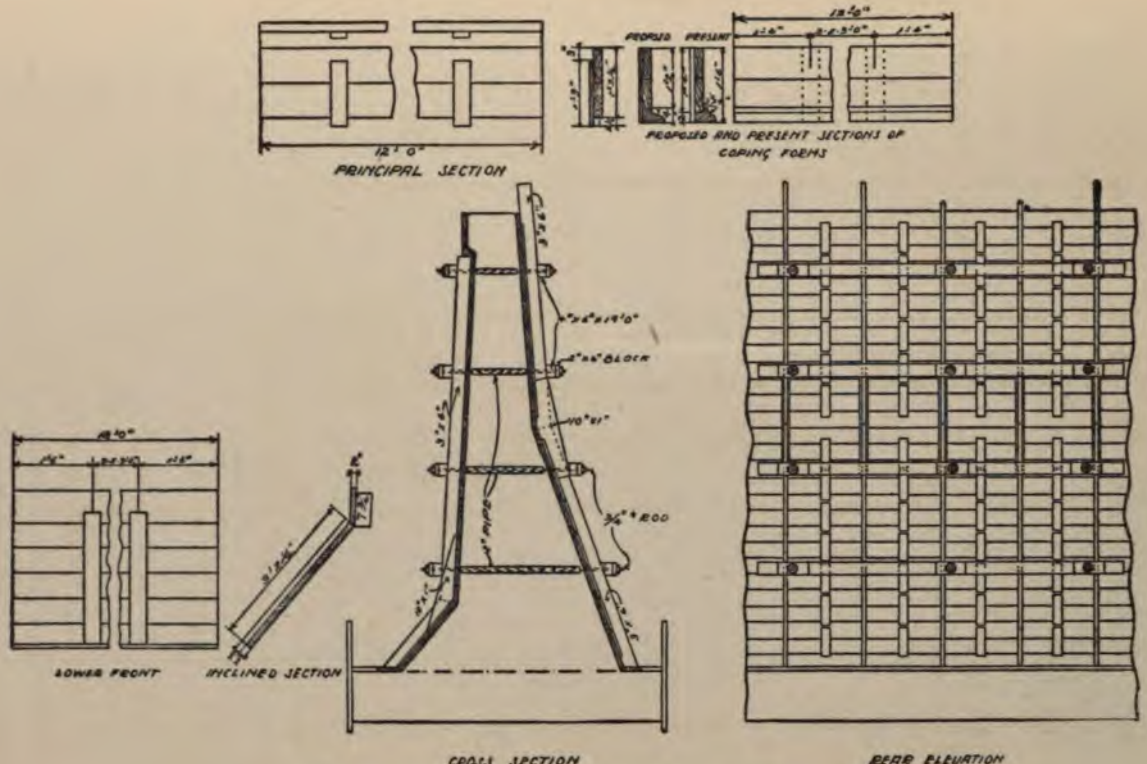


Fig. 89. Sectional Forms for Wall Shown in Fig. 88.

ing wall partially reinforced, as built by the Chicago, Burlington & Quincy Railroad Company for track elevation purposes in Chicago.

In Fig. 89 are shown the forms used on these retaining walls. They are a combination of continuous and sectional forms, the sectional part consisting of studs, coping, and bottom forms for the face, and sectional forms for the back of the wall. Ordinarily sheeting is used between the coping and bottom forms, the back forming being entirely sectional. All sections are made in templates, and delivered on the work in units, as shown in the figure. No attempt was made to use sectional forms on the face of the wall, except as mentioned, because the sections become battered and warped with use, do not fit closely together, and leave the wall rough when they are removed.

In Fig. 90 is shown the method of bracing and tying down the forms. The cross-section of the wall is such that the wet gravel concrete used had a tendency to lift the forms off the footing. This did occur in one case, causing considerable trouble. The plan shown in the illustration was then adopted, the bars being placed in the footing, and the forms tied to them with wires. In building such walls, it is difficult to keep them in perfect alignment. Small variations in the face of the wall are not noticeable, but any deflection of the coping shows at a glance. The method of bracing the coping form

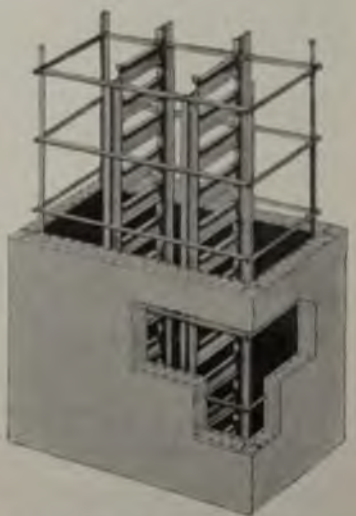
Courtesy of Calvin W. Hendrick, Chief Engineer, Sewerage Commission, Baltimore, Md.

LARGE SIPHON UNDER OUTFALL SEWER AT CHASE AND WOLFE STREETS, BALTIMORE, MD.

One of the largest siphons in the world.

REINFORCED CONCRETE GRAIN WAREHOUSES, TUNIS, NORTHERN AFRICA.

Though having settled to extent shown, these buildings were restored to perpendicular without injury.



CONCRETE SHAFT LINING.

Used in construction work for the Detroit Salt Co.

Completed footings and column forms.

View showing interior of pocket.

CONCRETE COAL POCKET.

PLATE 25—CEMENT CONSTRUCTION.

shown in Fig. 90 furnished an easy and effective way of lining up that form.

Plate 14 (**A**) is an illustration of a counterfort retaining wall built by the Lackawanna

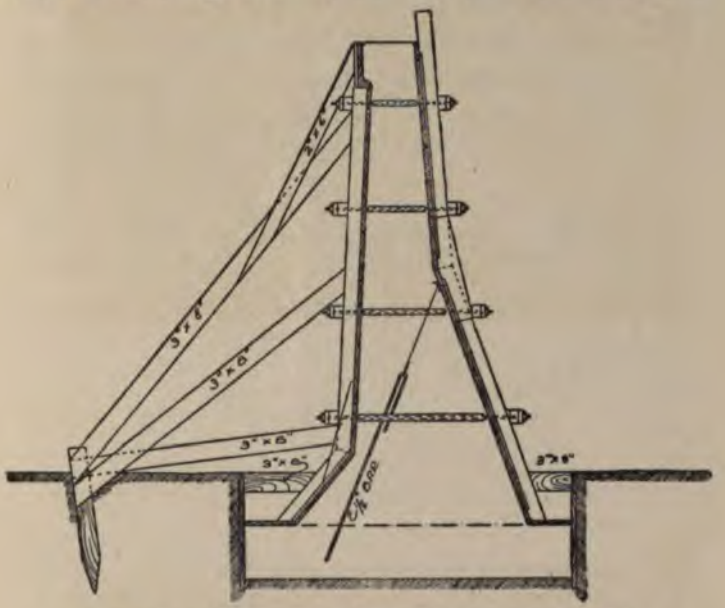


Fig. 90. Form Bracing for Wall Shown in Fig. 88.

Railroad in Buffalo, N. Y. This wall was built as part of the Buffalo track elevation work, and is 24 feet high (see Fig. 91). The same type of construction was used for all walls over 12 feet. For walls under 12 feet in height, the section shown in Fig. 92 was adopted.

The reinforcement of the buttressed section consists of both horizontal and vertical bars near the face of the wall, horizontal bars in the base, and inclined bars in the buttresses, square mild

steel being used in all cases. Those laid horizontally in the face of the wall are of 5/8-in. material spaced on different centers, farther apart at the top and closer at the bottom, to take care of the increasing pressures toward the bottom of the wall. The vertical bars in the front face are of 1/2-in. material spaced throughout on 2-ft. centers. In the back face, five 1/2-in. bars have been placed on 18-in. centers. Tie-rods

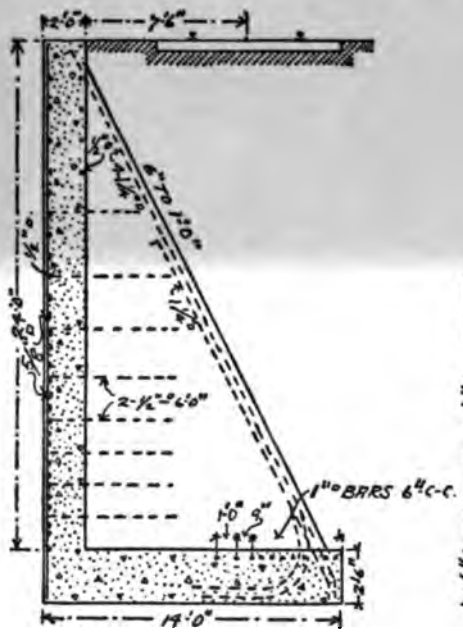


Fig. 91. Section of Counterfort Wall Shown in Plate 14.

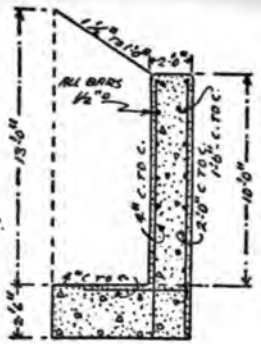


Fig. 92. Section of Low Wall.

run from the wall into each buttress, two of them being looped over every third of the horizontal face bars. They are 6 ft. long, and 1/2

in. square. The heaviest bars used on the work, 1¼ in. square, are used for the diagonals in the buttresses. There are eight of these; but only four run the entire distance from the top of the wall to the outer end of the base, the others starting at intermediate points. At the bottom of the buttresses, four of the diagonal bars are bent back toward the wall, and are embedded near the under side of the base. Running longitudinally in the top of the latter are 1-in. square bars, in the outer half of the footings. The rods in the face do not come closer than 2½ in. to the surface of the concrete; and those in the buttresses and in the base, not closer than 3½ in.

In order to preserve the proper spacing for the horizontal bars in the face a 2 by 2 by $^{3}/_{16}$-in. angle is placed in the face at each buttress, holes being punched in one leg to hold the bars in their proper positions. They are left in place, and form part of the permanent reinforcement of the wall. The horizontal bars are on 18-in. centers for the first 6 ft. down from the top, on 12-in. centers for the next 6 ft., on 9-in. centers for the next 5 ft. 3 in., and on 6-in. centers for the remainder of the distance to the bottom of the wall.

The reinforcement for the sections below 24 ft. and above 12 ft. in height, is substantially the same for all sections, except that the base would be moved upward, cutting off the lower part of the reinforcement shown in the diagram.

so that from the top down for any given distance the steel will be the same in walls of all heights.

The buttresses are 2 ft. wide, and 12 ft. 6 in. on centers. In the original design it was intended to place an expansion joint every 25 ft., or on the center line of every second buttress. When construction was started, however, it was found that the wall could be more economically placed in 50 ft. than in 25-ft. sections, and it was therefore decided to place the expansion joints every 50 ft., so that the day's work could be made to terminate at an expansion joint.

All of the horizontal bars are 28 ft. long, while the others, necessarily, are cut to shorter lengths in accordance with their positions. The concrete was a 1:3:6 mixture made with gravel.

For the lower walls without buttresses, the reinforcement is similar to that of the 10-ft. wall in the diagram. For this particular height it consists of ½ in. square bars in the base and in both faces of the wall. The vertical bars in the front face are on 2-ft. centers, and the horizontal bars on 18-in. centers; while in the back face the vertical bars are on 4-in. centers, and the horizontal ones on 18-in. centers. The bars in the base are placed horizontally on 4-in. centers, and run from the front of the wall back into footing.

Plate 14 (**B**) shows clearly the placing of part of the reinforcement before the concrete was cast. As will be noted, great care was exercised

in holding the steel in its proper place. A board notched on both sides with the proper spacing for the diagonal bars, was used to prevent the displacement of the steel. Similar notched boards were placed in the base to hold the bars in proper position, and at the upper ends of the diagonal bars in the buttresses. For the latter purpose, the notched piece was nailed to a bracket attached to the front form for the wall. The vertical and horizontal bars, in addition to these precautions, were wired at intersections so as to insure against displacement. The concrete was placed very wet, and on this account long ½-in. rods threaded at both ends were used to tie the forms together.

Although, on account of the soft nature of the ground along the right of way, all of the walls rest upon piles, no cracks have occurred. Of the maximum section, 24 ft. high, there is a total length of 1,700 ft.; and of this length, 1,000 ft. is in one continuous wall.

The following specifications for materials for reinforced concrete retaining walls are those given by one of the largest manufacturers of reinforcing material in the United States:

Specifications for Materials for Reinforced Concrete Retaining Walls

Cement. Only Portland cement conforming to the requirements of the specifications adopted by the American Society for Testing Materials, June 14, 1904, shall be used.

Sand. Sand to be clean and coarse, and free from organic matter; a graded sand, with coarse grains predominating, is to be preferred.

Coarse Aggregate. Broken stone to be hard, durable limestone, or its equivalent, free from dust and foreign materials; maximum-sized particles to pass through a one-inch ring; fines to be removed by passing over a one-quarter-inch screen. The fines may replace part of the sand. Under special conditions making for uniformity, crusher run may be used, but this is not desirable.

Gravel shall be clean and of graded sizes; the sand carried to be removed by screening as for broken stone.

Proportions of Mix. Concrete for wall, base, and buttresses to be mixed in the proportion of one part cement to six parts aggregate; proportions by volume, taking one bag containing not less than 94 pounds of cement, equal to one cubic foot of cement.

The proportions of fine and coarse aggregate used shall be chosen so as to give a concrete of maximum density; in no case, however, may the amount of fine aggregate be less than 50 per cent of the coarse.

Reinforcing Steel. All reinforcing steel used in retaining wall construction shall be rolled to such form that it has a positive mechanical bond with the concrete. Adhesive bond will not be considered sufficiently reliable for this class of structures.

Steel may be made by either the Bessemer or open-hearth process; bars to be rolled from billet stock. Re-rolled material will be accepted under conditions insuring rigid inspection.

The elastic limit and percentage of elongation shall be determined by tests on accurately-machined specimens, and shall conform to the following requirements:

Elastic limit to be from 50,000 to 60,000 pounds per

square inch, ultimate strength not less than $1\frac{1}{2}$ × elastic limit.

The percentage of elongation in 8 inches must not be less than given by the formula:

$$\text{Percentage of elongation} = \frac{1{,}400{,}000}{\text{Ultimate Strength}} - 5.$$

Bending Test. Bars as rolled shall bend cold, 90 degrees, to a radius equal to three times the least diameter of the specimen, without sign of fracture.

Representative Concrete Structures

As illustrative of the uses to which reinforced concrete has been put, we describe in the following pages, and illustrate in the accompanying plates, a few examples of the many types of structures which are becoming more common each day.

In the line of bridges, trestles, viaducts, culverts, and retaining walls, a large number of representative examples of concrete construction have already been given in the chapters dealing with those types of structures.

In Plate 15, we show the John Deere Plow Company's new building in Omaha, Nebraska. This building is of mammoth size, a half-block wide and a full block in length, spanning the alley, so that railroad cars run right through the building. This of course is a good feature in regard to shipping facilities.

The construction of the building is of reinforced concrete. It is a solid mass of concrete with massive columns and girders, and all heavily reinforced with steel construction. There is a regular network of steel beams, rods, trusses, etc., embedded in the concrete so that the latter forms a protection to the steel work and the steel work strengthens the columns and beams. Thus

the construction is one which is practical and of very great stability.

The building is eight stories high; at the time the photograph was taken, it was three stories high and work was progressing.

Railroad tracks are laid by the side of the building, so that carloads of material can be unloaded in the most convenient place. Then there is the big steam derrick, shown plainly in the photograph, and this ponderous machine will even pull the cars around and switch them. It will stand right in one spot anywhere on the track and turn itself around. It will swing the crane around to any position. It has an automatic scoop that will go down into the sand pile or the crushed stone, elevate it to the desired height, and deposit it anywhere at the will of the operator.

There are other lifting devices about the building, concrete mixers and modern up-to-date devices of various kinds for rapid and thorough work in construction. Every facility for rapid and thorough work seems to be amply provided for. The building is so large that the photograph covers only about one-half of one side of it, but the picture shows the method of construction. An immense amount of timber is used in the falsework, as can plainly be seen.

Men are busy at work building up the forms, and taking them down as soon as the concrete is sufficiently hardened. In this view but little of the falsework has been removed. The first story

left-hand corner shows part of the forms removed.

The floors of this building are a solid monolithic mass of concrete reinforced with steel.

The Milwaukee Auditorium. Among the finest structures in the northwest is the **Milwaukee Auditorium**—absolutely fireproof, as it is entirely of concrete construction with steel roof girders. The floors of the arena, also the stage floor, as well as all other floors, are of concrete, as well as all stairways. The clear size of the Auditorium room is 165 feet by 260 feet, and that of the arena, 110 feet by 225 feet. The arena is surrounded by a retaining wall 16 feet high and 650 feet in length.

The building proper rests on 1,500 piles, arranged in 270 groups, which are capped with reinforced concrete piers. A massive reinforced girder encircles the building, supporting the outside walls, which in some cases are 110 feet high.

The total concrete estimated for this building is 19,000 cubic yards, and about 500 tons of steel rods were required to reinforce this concrete.

The seating capacity of the Auditorium Hall is 12,000, and that of the stage is 500. In addition to the large auditorium hall, there are three smaller convention halls, one large dining hall and a cortege hall.

The size of the building is 312 by 295 feet; the height, 90 feet above grade; size of auditorium room, 165 by 260 feet; size of stage, 55 by 66 feet; promenade around auditorium, 12 by 700 feet;

longest concrete girder, 62 feet; main pillars, 2 by 2 feet.

THE FIRST CONCRETE SKYSCRAPER.

The building shown at the left in Plate 16 —the Ingalls building, Cincinnati, O.—is of special interest from a historical point of view at least, as it has the distinction of being the first skyscraper or high office building built of concrete. Regarding it, the "Architectural Record" (June, 1904) says:

"During the progress of the work on the Ingalls building, some men of great ability, who should have known better, predicted that the structure would never reach the roof, and that even if it did, it would certainly crack all to pieces by shrinkage, and that it could not possibly withstand wind pressure. The facts are that it did reach the roof; that there are no shrinkage cracks, and that the building not only has not blown over, but that in the highest winds there is not even a perceptible tremor, and that, too, with concrete walls only 8 inches thick from bottom to top, and the floors but 5 inches thick in unbroken slabs 16 feet square, a portion of which, on the second floor, carries a bank vault weighing nearly a hundred tons."

The building occupies the northeast corner of Fourth and Vine streets, 50 feet on Fourth and 100 feet on Vine street; there are 15 stories and an attic. In the construction, so-called structural steel is entirely dispensed with, reinforced concrete being used. All structural parts, such as columns and their footings, girders, beams, floors, roofs, wind-bracing, and stairs, and the exterior walls, except the face work, are

of concrete 8 inches thick, reinforced with steel rods embedded in the concrete. The floors consist of slabs 16 feet square and 5 inches thick, without any other supports than the beams at the edges in this area. The retaining wall under the sidewalk supporting the street is constructed in a similar manner, being figured very much like a floor set on edge.

The exterior faces consist of a veneer of marble for the first three stories, and enameled brick and terra-cotta for the remaining stories.

Metal sash is used in all the windows throughout, and cement trim around doors and windows instead of the usual wood. The base around the rooms is also of cement.

A MODERN APARTMENT HOUSE.

The monolithic reinforced concrete skeleton frame of a modern apartment house is shown at the right in Plate 16. From the footings to the roof, the entire framework is solid concrete reinforced with trussed bars. All the floors are of reinforced concrete and hollow-tile construction.

Besides the advantage of its economy of materials and time, this construction has other marked advantages for such a building as this. One of these is its insulating properties. Dry air is an excellent insulation, and the air contained in the hollow spaces of the tile is a most excellent medium for preventing the passage of heat. For the same reason all the interior walls

and partitions are built of hollow partition tile, thus insuring not only even temperature but freedom from noise as well, for the hollow tile is an insulation against sound as well as heat.

The floors of the bay windows are cantilevered out over the wall beam at each floor. This is accomplished by inverting Kahn bars in the top of the projecting slab and allowing these bars to run well back into the regular floor-slab. The cantilevered slabs carry the wall and windows of the bays from the second floor up. On the side of the building, two balconies are carried in the same way from the fourth to the seventh floor. The cantilever is much greater, but tests have shown that the floors are equal to sustaining a greater load than any that will ever be put upon them.

The photograph shows the outside brickwork just being started in the front. At one side the outside wall is already up six stories. These walls are carried on the floor beams at each floor, while a single veneer course is carried all the way up on the outside in order to hide the skeleton entirely. In this way all the beauty of high-class masonry is combined with the strength and stability of reinforced concrete.

The exterior finish is brick and stone, and presents very pleasing elevations. The interior is sound-proof, vermin-proof, and fireproof—a combination of highly desirable features.

A Modern Hotel. The Marlborough-Blenheim Hotel at Atlantic City, N. J., shown at the

top of Plate 17, is one of the largest reinforced concrete buildings in the United States. The width varies from 60 to 200 feet, and the entire length is 560 feet. The main building is nine stories high; the front, with the dome, thirteen stories.

Rapid and noiseless construction was absolutely necessary. Speed was required because immediate use of the building was of great importance. Reduction of noise was required as guests were being entertained in the older portion of the hotel. For this reason structural steel was out of the question.

Reinforced concrete was used in all footings, columns, beams, floors, roof, and dome. The floors are of reinforced concrete and hollow-tile construction, varying in thickness from 4 to 12 inches. The cantilevered balconies, turrets, dome, arches, etc., as well as the other decorative features, were carried out in concrete.

All exterior walls and all partitions are of hollow partition tile laid in mortar. Plaster is applied directly to the tile surface on interior partitions, and elaborate decorations in the lower floors are applied directly to the tile and concrete surfaces.

A Factory. Plate 17 shows, in the center, the Minterburn Mills at Rockville, Conn. This woolen and worsted goods mill, 58 by 294 feet, four supported floors and roof, was erected in 70 days by the use of reinforced concrete.

The entire building—footings, columns, girders, beams, floors, roof, and walls—is of concrete reinforced with trussed bars. The concrete pilasters between windows are 7 feet 6 inches on center; and each one supports a floorbeam. The columns of the row down the center, dividing the building into two bays, are 15 feet on center. Intermediate beams span 29 feet from wall to center girder and columns. Between these beams is the 4½-inch solid concrete floor-slab.

The low curtain walls under the windows and the wall panels at the end of the building are solid concrete. The wall at the end is built around a stairway. All the stairways in the building are completely enclosed by firewalls, and all openings are provided with automatic fire doors so that each floor is entirely separated from the others. With this protective system the entire contents of one floor might burn without damaging the stock or machinery in the rest of the building.

Adjoining the main building are two other buildings—the dye house, 39 by 66 feet; and the engine and boiler house, 50 by 78 feet. The dye house has a perfectly clear floor, as the beams which support the 6-inch solid concrete roof-slab span from wall to wall, 39 feet clear. These beams are 15 feet apart. A monitor running the full length of the building rests on them.

The boiler house is divided into two rooms—the engine room, 50 by 30 feet 6 inches; and the boiler room, 50 by 47 feet. Both of these rooms have unbroken floor areas, the engine-room roof-beams spanning across the 30-foot 6-inch way, while in the boiler room the beams span 50 feet from outside wall to outside wall. The great advantage of large clear floor areas in buildings of this kind, especially in engine rooms, is apparent, as engines, pumps, etc., may be placed anywhere on the floor without regard to the limitations of the structure.

When it is remembered that this building, permanent and fireproof, was erected in only 70 days, the revolution

in construction which reinforced concrete has brought about is more forcibly emphasized than ever.

A Cold-Storage Plant. Plate 17 shows at the bottom, a modern cold-storage warehouse and refrigerating plant, approximately 160 by 160 feet, erected entirely of reinforced concrete.

The building has seven full stories and a mezzanine floor in the first story. The first and second floors have solid concrete slabs reinforced with trussed bars in both directions. They are designed for a live load of 330 pounds per square foot. All other floors and the roof are of reinforced concrete and hollow tile, its cheapness and the speed of handling this form of construction deciding in its favor even after designs for solid concrete floors had been made and accepted.

Every precaution has been taken to insulate the building thoroughly. On the tile floors of the storage portion 2 inches of pressed cork is laid; and above this 3 inches of concrete is laid with the surface finished smooth. All interior partition walls are built of two thicknesses of hollow tile with a filling of ground cork between.

The construction of the exterior walls is unique in that there is really a building within a building. Walls of hollow tile were built on each floor, being supported by the floor construction. Outside of these walls and entirely independent of the reinforced concrete building, except for occasional anchors, another hollow tile wall is carried on cast iron columns and a steel frame. In this way the outside wall and its supporting frame are free to expand and contract with changes of temperature, while the inner wall and concrete skeleton will be entirely unaffected.

One portion of the building, 31 by 97 feet, is built entirely independent of the remainder, although the same exterior walls enclose it. This is what is known as the "machinery section," and contains the boilers,

CONCRETE BLOCK CHIMNEY.

WATER INTAKE 185 FEET HIGH.

PLATE 26—CEMENT CONSTRUCTION.

WATER TOWER AT ANAHEIM, CAL.

PLATE 27—CEMENT CONSTRUCTION.

CONCRETE LIGHTHOUSE, MILE ROCK, SAN FRANCISCO BAY.

engines, and refrigerating machinery. This section has its own reinforced concrete frame carrying the outside walls, and there is an air-space between these walls and those of the main building.

There are no columns above the first floor in the machinery section, the beams supporting the successive floors spanning from wall to wall, giving ample room for the proper arrangement of machinery. In one portion of this section, two pieces of refrigerating machinery weighing 40 tons each rest on the floor. When these were put in place, careful observation was made to determine their effect upon the construction; but absolutely none was noticeable.

The two lower stories are veneered with paving brick, while all other exterior walls have a plaster finish applied directly to the tile walls. A terra-cotta belt-course covers the steel skeleton of the outer shell, and a terra-cotta cornice finishes the top of the wall.

A Train Shed. The Bush Train Shed at Scranton, Pa., shown in Plate 18 (at left) illustrates a very interesting application of reinforced concrete. In describing this construction, the "Railroad Age Gazette" says:

"The Bush train shed consists of longitudinal units meeting over the tracks so as to make a continuous structure, except for the narrow openings, or smoke ducts, over the locomotive stacks. The roof is supported on longitudinal rows of columns, 27 feet apart on centers, resting in the reinforced concrete platforms. The transverse main rafters are continuous between the columns, and form the only breaks in the continuity of the openings over the smokestacks. The vertical clearance from the top of the rail to the under side of these main rafters at center line of track is 16 feet 6 inches. Framed to these rafters are longitudinal purlins which support the

reinforced concrete roof-slabs and the skylights. Between the columns are longitudinal girders supporting the inner ends of the intermediate rafters, whose outer ends are riveted to the framework of the smoke-duct purlins. This framework consists of a pair of light, latticed purlins. The longitudinal girder between the columns is built up of two channels and a plate, forming a trough, which is lined and sloped with concrete with a surface finish of copper, and serves as a rain-water gutter. The girder is braced at the columns with gusset-plate and angles, built up with a curved flange corresponding to that of the main rafters, so that the four members spring away from each column on harmonious lines. The columns are of cast iron, and the roof framework of wrought steel. The weight of the metal complete per square foot of shed area, including columns and anchor bolts, is 20.09 lbs. The roof-slabs are of concrete, 2½ in. thick, reinforced with 3-in. No. 10 expanded metal, the finished surface being four-ply slag.

"The steel framework of the smoke ducts and the main rafters where they pass through the smoke ducts are encased in concrete. This concrete casing is reinforced with expanded metal. At the ends of the shed, and at cornices along the two sides of the shed, all metal work is encased in concrete. The sides of the ducts are high enough to prevent driving rain or snow from reaching the platforms. The longitudinal gutters mentioned above are drained by leader pipes running down inside every other supporting column, where they connect with drains under the platforms. The air-space between the inside of the columns and the outside of the drain-pipes insulates them from freezing, and the drain-pipes are not exposed, adding to the appearance of the shed and eliminating possible damage to drain-pipes from baggage trucks. The electric lights are arranged in longitudinal lines between the columns. Arc-lights were installed for temporary use only. In daytime, ample light reaches the

interior through the skylights and the smoke ducts.

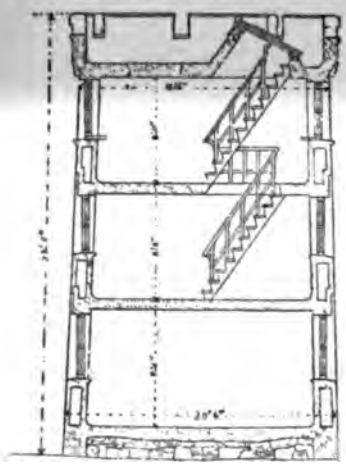
"The main advantages of these sheds are: first, the original cost is much less, being about 40 per cent less than the cost of a high-roofed shed in the case of a large terminal; second, cost of maintenance is very much less; third, there is more light; and, fourth, there is no smoke or gas inside the shed, and much less noise. One of the large items of saving is in maintenance cost of painting. The steel work is never exposed to engine gases and smoke. At the smoke ducts, where it would be in contact with these gases, it is protected by concrete. In the walls of the duct immediately under roof-slab are small flues which allow any gases which might get behind the smoke duct, or any heated air rising from the platform level, to escape to the duct and thence to the open air. When paint is required, high scaffolding is not needed, which means a further saving. Aside from material, there is a saving in the first cost of the shed because of the ease of erection. Everything can be handled by derrick cars, doing away with falsework, and the work is easily carried on without interference with traffic or inconvenience to the public.

"There are skylights on each side of the smoke ducts, admitting light directly to the windows of the cars on the track below. The frame of the skylight is a small channel, on which, at intervals of 18 to 20 in., are fastened malleable iron bridges or stirrups. These support flat iron bars with elongated holes engaging brass studs screwed into the stirrups. The glass plates rest on sheet-metal guides, strips of cow-hair felt being laid between the glass and the guides as cushions, while on top of the glass are corresponding strips of felt, held in place by sheet-metal guides. No putty or cement is used. Three-eighth-inch glass is used. In the Hoboken shed, similar to this, sheets of glass 27 in. by 86 in. were used. In the Scranton shed, the sizes were cut down to 20 in.

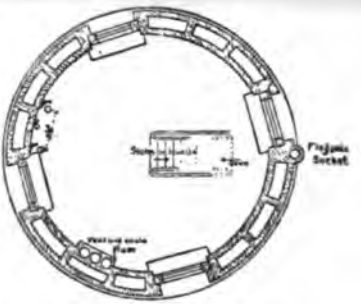
by 60 in., which is now believed to be the best size for skylight work.

"The roof of the Bush shed is accessible for painting, cleaning, or removal of snow. If snow is removed from the roof, it may conveniently be shoveled through the smoke ducts into gondola cars beneath."

An Observatory. There has recently been completed on the top of Blue Hill, a few miles from Boston, a **reinforced concrete observatory** which presents some interesting features aside from its stability. One of the essential elements required in the design was absolute resistance to the entrance of water under the conditions of heavy, beating rains at very high velocities.



Longitudinal Section.



Section at Third Floor.

Figs. 93 and 94. Blue Hill Observatory, near Boston, Mass.

The observatory is of circular section, 17 feet 6 inches inside diameter, 20 feet 6 inches on the outside, and 33 feet high (Figs. 93 and 94). The walls are of double thickness of 4 inches each, separated by a 10-inch air-

space, which provides an absolute means of preventing the passage of water.

Reinforced concrete was selected on account of its many advantages, important among these being its unyielding stability, freedom from vibration in high winds, and its water-tight qualities, so necessary in a location where wind velocities range up to 80 and even 100 miles per hour. Expectations have been so fully realized that the action of the self-recording instruments has been entirely free from the unknown errors which were caused by the rocking of the old observatory, and there have been no signs whatever of leakage.

The observatory is built on a ledge, the walls being bonded thereto; the floor is slightly raised to provide an air-space beneath. A separate 4-inch granolithic finish was put on top of the first floor to provide a smooth tread, as well as to prevent any possible access of moisture. The general concrete mixture was 1:2:4.

Steel reinforcement consists of ¼-inch square twisted bars, spaced nine inches on centers, running in directions at right angles to each other, embedded in the concrete near the surface and extending into the wall.

The second and third floors and the roof are 6 inches thick, reinforced with ½-inch square twisted rods at right angles to each other and projecting into the wall. Those for the second floor vary in spacing from 12 inches on centers at the circumference to 5 inches apart at the center. Steel reinforcement for the third floor and roof is practically identical with that of the second floor, but with an added number of bars on each side and at the middle end of the stair openings and roof scuttle. The reinforcing bars are placed close to the bottom of the floors, while those for preventing cracks close to the wall are placed near the top, being bent up at the wall and hooked over the nearest inside horizontal wall-bar. All floors, including the roof, are granolithic finish.

The inner and outer 4-inch walls are reinforced to

of the second floor by ¼ and ⅜-inch twisted
ve this, ¼-inch bars are used entirely, except
⅜-inch bars are placed for strengthening the
socket. Concrete webs at 3-foot intervals con-
the inner and outer walls, reinforced and connected
them by Z-bent ¼-inch bars.

stairs are of wood, with wrought-iron railings.
scuttle is provided with a window for observation
wet weather. The windows are in all cases double-
d and tight-fitting. For taking outdoor temperature
winter and for other purposes, a wooden set shelter is
tened to the sill of the second story window facing
north.

Heating is provided for by a fireplace and grate on
first and second floors. One flue for both is built
o the wall on the southeast side. Close to this are
o other flues, to be used for ventilating purposes. All
es terminate flush with the top of the parapet. Louver
mpers are used for regulating the opening of the ventilating flues.

From an architectural point of view the new tower is very attractive. The smooth, clean-cut concrete work, with picked finish, brings out the simple but effective design, decidedly appropriate in a structure of this kind.

Boat-House and Garage. The boat-house illustrated in Plate 19 is unique in combining with it an automobile garage on the second floor. It is located at Madison, Wis.

The building is 16 by 30 ft. The foundations are 2 feet 6 inches below water level, and the channel walls extend 5 feet 6 inches below water level. No reinforcement was used in the foundations or in the ground floor. The work under water was done while there was yet ice in the lake, and no waves to contend with, so that the cofferdamming was comparatively easy. The reinforce-

ment in the walls consists of ½-inch round rods 16 inches center to center, and fencing. The reinforcement for the second floor and roof was ½-inch rods, 12 inches centers, and the fencing brought over from the walls so as to make the walls and floor (also roof) as near one piece as possible. The roof is flat, sloping toward the rear. It is at present finished in rough concrete, but is intended to be finished with tar and gravel applied directly on the concrete without the use of paper. The concrete was mixed sloppy and poured into rough plank frames, and the outside walls were plastered "English rough-cast" after the framing was removed. The framing under floor was left 29 days and under roof 24 days. The building is a boat-house below, with a channel extending into the house, and a water gate hung on a concrete weight, that slides up and down in and out of the water, running in an angle-iron track that is embedded in the concrete. The upper floor is intended for an auto-house, and the incline is constructed of reinforced concrete the same as the rest of the building. The pier is 20 feet long, and was constructed November, 1904, and has stood the ice without the least sign of any breakage. There is not a particle of wood in the building, and only what can be seen outside (that is, door and windows). The total cost was less than $600.

A Baseball Grand Stand. Cincinnati boasts of having the first concrete baseball grand stand built in the United States. The structure, shown in Plate 20, is absolutely fireproof and as nearly indestructible as solid concrete work can make it. There are also covered bleachers built of concrete. This novel, handsome structure was built at an immense cost, but the concrete is paying for itself in the fact that no repairs are needed, and the work stands like a solid mass

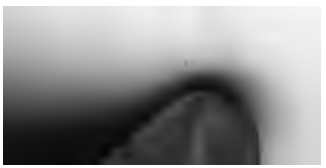
of stone. High water floods the foundation work almost annually, but no damage has been done.

No columns obstruct the view, other than those shown in the photograph, for concrete arches do away with the necessity of the heretofore indispensable roof supports.

A Coal Hopper. Plate 18 shows a coal hopper built for the Central Heating Company of Detroit, Mich. These hoppers, the design of which consists of steel framework which carries a concrete slab reinforced by the Gabriel system, are intended to carry a load of 1,200 tons of crushed coal. The design shows a combination of reinforced concrete and structural steel which is economical, durable, and easy of erection.

Concrete-Lined Tunnel. Plate 21 shows the style of forms and methods used in the construction of the 12 by 13-foot bore underneath the Chicago Postoffice from Adams street to Jackson boulevard. On account of the excessive weight overhead, this tunnel was built in small sections, which accounts for the small ribs inside of the larger ones. This construction consists of four small tunnels—namely, two side sections, one lower center section, and one upper center section. This style of construction will appeal to engineers and contractors who may have large work of this kind, as a large tunnel can be built as easily as a smaller sized bore, through soft ground and where heavy weights are encountered overhead.

Reinforced Concrete Sewer. Through the



courtesy of Mr. C. W. Hendrick, Chief Engineer of the Sewerage Commission of Baltimore, Md., we are able to reproduce cuts showing details of a **large outfall sewer** recently constructed in that city. The frontispiece of this volume shows not only a section of the completed work, but also the forms and reinforcement for a section on which the concrete has not been placed. It is well to notice the care which is exerted to keep the network of twisted rods, which were used in this construction, rigid and in their proper places. Notice also the length of lap allowed at ends of bars where they join others.

Plate 22 shows an end section of the completed work. Notice the likeness to an arch in the top part of the section. The inside dimensions were 11 feet by 12 feet 3 inches.

Regarding the great engineering problem which confronted the city of Baltimore in the development of a modern sewerage system, Mr. Hendrick, the chief engineer, writes as follows:

"Baltimore, one of the oldest and most aristocratic cities in the country, has allowed itself to grow to a size of 700,000 people without a sewer system, depending on the old methods of disposing of sewage by means of cesspools and otherwise. The State of Maryland has recently passed laws forbidding the discharge of sewage into the Chesapeake Bay or its tributaries without first purifying it, bringing the city face to face with one of the most stupendous engineering projects of modern times—that is, the installation of a storm-water and a sanitary sewerage system throughout the streets and alleys of the entire city, carrying connections to each individual house.

"We expect to spend somewhere in the neighborhood of $20,000,000 to carry the sewage to great disposal plants, in which the sewage will be brought to a state of purification equal to drinking water before discharging it into Chesapeake Bay. In carrying out this great project, some of the sewers are of such size as to remind you of the ones in Paris.

"In order not to have to purify the storm-water that falls, two systems—one for storm-water, and one for sanitary sewage—are being constructed. This, in some cases, causes two large sewers of the different systems to come together on the same level, necessitating the siphoning of one beneath the other. Plate 23 shows one of these siphons—one of the largest in the world—constructed along such unique lines of engineering as to have caused wide comment in the engineering world.

"The great trouble with siphons is brought about by having to make the siphon large enough to take care of a heavy cloudburst, and still be operative during the summer flow, when there is a mere trickle, causing deposits to accumulate in the siphon. In this case a battery of pipes is used in connection with dams, the small pipe being for the summer flows, which keep it under pressure. Should a rain cause the flow to increase, it rises over a dam, discharging into a larger pipe, with still another pipe in reserve, with a higher dam, to take care of a cloudburst; thereby putting all the pipes under pressure, scouring them out by the water pressure. As the storm recedes, each pipe is put out of commission in the reverse order, until the flow is back in the small pipe, which pipe is under constant pressure from the dry weather flow.

"Concrete is being used to a great extent, and wonders are being moulded under the city with this concrete construction. Our system will cover in the neighborhood of 1,100 miles."

A recent example of the inherent strength

and wonderful tenacity of reinforced concrete structures is found in the grain elevators erected at Tunis, in Northern Africa, shown in Plate 24. Owing to unequal settlement, the two outside buildings tipped as a whole away from the central structure, until in one case an angle of 25 degrees from the vertical was reached. Both buildings were returned to a vertical position by loading the elevated sides with sand, and at the same time making excavations along the foundations on the same side. Throughout this severe test the buildings remained whole and intact.

Plate 21 shows a cofferdam constructed of steel sheeting in the city of Chicago for the foundation of the Randolph Street bridge over the Chicago river. It was necessary to construct the cofferdam 85 feet long and 75 feet wide. The sheeting was driven alongside of the building known as the old Linn Block. About 1896 this building was considerably damaged by fire, but even in the face of this, the steel sheeting was driven alongside of the foundation to a depth of 31 feet below datum. The mill was in operation during this time, and the foundations were constructed without any damage whatsoever to the building. It is conceded by engineers and architects that the building is in better condition now than it was before the foundations were constructed. This illustrates the use of steel sheeting, and also shows a right-angle corner of the cofferdam constructed with interlocking steel sheeting; the I-beams being standard

I-beams, 18 inches wide, weighing 55 pounds to the foot; the channels being 15-inch channels and weighing 33 pounds to the foot. The right-angle turn was made by riveting two I-beams together, forming an L.

Miscellaneous Uses of Reinforced Concrete

In other chapters the main points in reinforced concrete construction work are treated. The use of reinforced concrete is becoming so general, and its possibilities are so numerous and of such a varied description, that in this rapidly advancing stage of the use of the material it is practically out of the question to cover every possible application. The fundamental and essential principles do not vary to so great an extent.

The following pages are devoted to the description of a number of instances where reinforced concrete has either displaced some less stable form of building material, or has proved an innovation in a certain form of construction.

Concrete Coal Pocket. The use of reinforced concrete as a structural material is extending rapidly, and owners contemplating building are getting away from the old lines, out of the rut, as it were, and erecting structures which have all the advantages of the old method, none of their disadvantages, and at the same or a slight additional cost obtain a genuine fireproof structure on which it is a waste of money to carry insurance, and on the contents of which the cost of insurance is only a small percentage of the cost

for the same material in a structure which can easily be destroyed by fire.

One of the many novel uses to which reinforced concrete has been put is the construction of large coal pockets for the storage of anthracite coal.

One of these pockets has been constructed for the Lehigh & Wilkesbarre Coal Co., at Charlestown, Mass., and is capable of holding 10,000 tons of coal. It is shown in process of construction in Plate 25. The owners decided to construct of concrete in order that they might have a building which would last for all time—one on which there would be no maintenance charges, and which positively could not burn down.

On the site of this new pocket there was originally a wooden pocket which was in use up to the time the construction of the new pocket was commenced. The old pocket had been erected about twelve years previously, and it was costing $1,000 each year to keep it from falling down—an equivalent of 5 per cent on an investment of $20,000.

The new pocket is 182 feet long, 92 feet wide, and 24 feet deep, and is set up on square columns arranged to allow the construction of paved driveways 13 feet wide, with a head-room of 10 feet 6 inches under the pocket, so that, in loading, a team may be driven through any of the driveways under the pocket containing the grade of coal desired. Upon reaching the proper chute, the driver pulls a lever, releasing the coal, which passes over a screen into the wagon, giving a load of clean coal in the shortest possible time. In this way it is

possible for a retail company to do the same amount of business with two-thirds of the teaming, compared with the old method of shoveling into wagons from storage piles.

The pocket was located on a filled area between two bulkheads, allowing a width of about 40 feet on one side. On the other side the wall of the pocket was located on the bulkhead line which necessitated filling out into the slip a width of 30 feet for a driveway. With such a great dead weight as the pocket and the coal, it was, of course, impossible to construct the foundations directly on the fill, as the probability was that there would be uneven settlement and possible serious damage to the pocket. It was therefore necessary to build a pile foundation, as the absence of any firm bearing stratum precluded the use of deep footings owing to their prohibitive cost. It was eventually determined to use concrete piles, these being more desirable in every way than wooden piles and actually costing less money.

In the event of using wood piles, the building laws would have required that they be cut off 10 feet below the surface of the ground, and a load of only ten tons could be carried on each pile. This would have necessitated the use of three times as many wooden piles as concrete, and required an enormous amount of excavation, bracing, and additional concrete to carry the footings down to grade. Necessity of tide work would have made the use of wooden piles more expensive and awkward, because the excavated trenches would have filled with water at each rise of the tide, necessitating pumping, submerging fresh concrete at each tide, and making progress slow and difficult. The construction of a cofferdam around the site was out of the question because of the expense involved. Concrete piles were selected because of their unquestioned durability and their greater supporting power and economy.

Seven hundred and fifty piles, varying in length from 20 feet to 40 feet, were driven by the use of two 50-foot drivers. These piles are of a uniform diameter of 16 inches and are composed of a mixture of 1 part Portland cement, 2½ parts sand, and 5 parts one-inch trap rock. In placing these piles, the driver is brought to the proper position over the pile location, and a hollow steel form, 16 inches in diameter, fitted at the bottom with a blunt, detachable cast-iron point, is driven until the required penetration is obtained. Sufficient plastic concrete for the length of the pile is then poured into the form, and the form withdrawn, allowing the concrete to settle down into the hole, coming into intimate contact with the surrounding ground, cementing itself thereto and forming a rugged, monolithic column 16 inches in diameter from top to bottom.

The heads of these piles protruded 6 inches into the reinforced concrete footings, which were 2 feet 6 inches thick, and on which were constructed concrete column bases 4 feet by 4 feet by 10 inches.

A hoist and tower was erected over the mixer; and an incline, equipped with industrial railway and car operated by cable, was constructed from the storage piles of sand and stone to mixer. The concrete was raised to the desired height in the tower, and discharged into a chute fitted with a gate. The concrete was drawn from the chute into industrial cars of about 18 cubic feet capacity each, pushed by hand on tracks to the point of pouring.

The concrete for the structure was mixed in a large mixer and in the proportions of 1 part Portland cement, 2 parts clean, coarse sand, and 4 parts ⅛-inch to 1½-inch crushed trap rock. All concrete was mixed to a jelly-like consistency, and when placed was thoroughly worked with spades and other tools to increase the density of the concrete and to work the mortar to the forms so

CONCRETE TANKS IN A LARGE TANNERY.

THE GREAT CATARACT DAM, SYDNEY, N. S. W.

that when they were removed the surface of the concrete was smooth and free from voids.

The forms for this work were made of spruce, and were built in units at the mill and shipped to the site of the work, where it was only necessary to assemble the various units and support same. This proved to be a very satisfactory and economical method.

The reinforcing steel was delivered on the site of the work and consisted of straight cup bars. Bending of the bars was done by hand, cold, at a very small cost. In placing and assembling, the steel was thoroughly wired together to prevent displacement during the placing of concrete.

On the column bases, the column reinforcement was erected and enclosed in a column form, and the forms for the slabs, girders, and beams were then erected, supported and braced. The columns were then poured with concrete to the under side of the girders and allowed to harden and set for at least twenty-four hours. During this period the steel reinforcement for the girders and beams was placed, and eventually these members were poured, and also the floor-slabs, the reinforcement for which was placed during pouring. The surface of the slab or floor was troweled to a smooth wearing surface while the concrete was soft. Previous to pouring the slabs, boxes at the location of the openings in the floor for the chutes were set and secured, into which openings cast-iron hoppers were finally placed.

There were left reinforcing rods protruding, to which other rods were spliced as reinforcement for the walls. The forms for the walls were set up in sections to a height of about 6 feet, the reinforcement placed and secured, and forms well braced and the work then poured.

The pocket is divided into twelve separate compartments, one division wall running the entire length through the center of the pocket, and partition walls

every 30 feet apart transversely across the pocket, making pockets 30 feet by 45 feet in dimension. These division walls are 2 feet in width at the bottom and 1 foot in width at the top, and are designed as cantilevers, the steel being placed vertically and anchored in the girders. Sufficient horizontal steel was used so that cracks would not develop. The outer walls are 12 inches thick at the bottom and 8 inches thick at the top, and are 24 feet high. They are stiffened with buttresses every 10 feet. These buttresses extend into the pocket 7 feet at the floor level, and run to within 8 inches of the line of the wall. They are 10 inches wide and reinforced with nine steel rods on the outer face, running down into a beam for anchorage. The walls between the buttresses were designed as beams and the steel was bent in at the buttresses and held by rods anchored into the buttresses.

A wooden roof with a tar and slag covering encloses the top of the pocket, protecting the coal from rain and snow.

A new trestle 50 feet in height has been erected, and from this lead four automatic railways, no other power than gravity and a weighted triangle being necessary for their operation.

On the interior of each pocket, under the tracks, has been erected a series of deflectors on an 8-inch pitch, each deflector being constructed of wood, and protected against excessive wear by sheet iron. The coal slides from one deflector to the next lower, and in this way prevents a straight drop of the coal to the concrete floor below, thereby reducing the breakage to a minimum.

Transversely across the building on each side of the lower columns a reinforced concrete wall 4 inches thick has been constructed, forming dirt pockets. These pockets receive the screenings from the coal as it runs over the screens in the chutes. These screenings are shoveled out through openings in the bottom of the dirt

pockets into carts and taken to a screening plant, where they are deposited in a large hopper and discharged onto a vertical bucket-conveyor, carried up and run through a revolving screen and separated into the smaller sizes of coal. This plant is electrically operated.

Under the pocket in all driveways, granite block paving with grouted joints is laid on a gravel base. This paving runs also 30 feet out from either side of the pocket, around and under the screen house, and up to the scales and office.

Under the pocket in each bay is a 16-candle-power electric light, and under the roof over each separate pocket is a light and a reflector.

Water-Intake. A concrete water-intake of unique design, claimed to be the only one of the kind in the world, has recently been completed near San Bernardino, Cal., for the Arrowhead Reservoir and Power Company. The intake or tower (shown in Plate 26), which is built entirely of reinforced concrete, is 185 feet in height, 13 feet in diameter, and stands in an artificial lake in mountainous country at an altitude of nearly 6,000 feet above sea-level. The wall of the tower to the height of 125 feet is 24 inches thick; and from that point up, 15 inches thick. The cement, sand, and crushed rock to make the concrete were mixed in the ratio of 1:2:3, and the reinforcement consists of three-fourths-inch rods running circular and perpendicular. The tower was constructed in sections of six feet each, and was completed in about six months, at a total cost of about $40,000.

The Arrowhead Reservoir and Power Com-

pany, which for nearly twelve years has been working on a great dam at this place, had been experiencing difficulty for some time to keep the old intake clear of rubbish, which, on account of the strong suction, at times almost entirely shut off the flow of water. The new intake overcomes the problem with a series of ten 20-inch valves, arranged on the sides of the tower in spiral form from the top to near the bottom, so that the water can be taken in at any level. The intake stands in an 880-acre artificial lake that at present has a depth of over 35 feet, and that is subject to great fluctuations. The valves can be controlled from the top of the tower, and by the opening or closing of the different valves both the quantity and the pressure of the water can be readily and quickly regulated. Each valve is inclosed in a circular screen cage about 5 feet in height and 2 feet in diameter, seated on an elbow which turns up on the outer surface of the tower.

Concrete Chimneys. The first reinforced concrete chimney was built in 1898 by the Ransome & Smith Company for the Pacific Coast Borax Company, Bayonne, N. J. Since that time about 400 stacks have been completed. There are examples in nearly every State of the Union and in Canada. These stacks range in height above ground from 50 to 352½ feet, with inside diameter ranging from 4 to 18 feet, the majority of them being 150 to 200 feet high and 5 to 6 feet inside diameter.

One of the tallest chimneys in the United

States is of concrete construction and located at Butte, Mont., at the mines of the Colusa Parrot Mining & Smelting Company.

The stack is 352½ feet high; its inside diameter, 18 feet. The walls of the lower 21 feet of the chimney are 18 inches thick; and above this is the double shell, the outer shell being 9 inches and the inner 5 inches thick, with a 4-inch air-space between them. The inner shell extends to a height of 101 feet above the base. The vertical reinforcement is 1¼-inch by 1¼-inch T-bars; and the horizontal reinforcement, of 1-inch by 1-inch T-bars, varies in spacing from 12 inches to 3 feet apart. A very rich mixture was used in the construction. The foundation of the chimney is unusual, consisting of a base 18 feet in depth, formed of molten slag in which steel wire rope, chain, and T-rails are embedded, and upon which is placed the reinforced concrete footing for the chimney proper.

The cut in Plate 26 will no doubt be of much interest as showing the great versatility of concrete blocks and the many purposes for which they are now used which were probably not dreamed of in the earlier stages of the industry. The smokestack shown is located at Cooks Ferry pumping station of the Southwestern Pennsylvania pipe lines. It is 120 feet over all, and has an inside diameter of 4 feet. It is lined with an inner shell of firebrick laid up in fire clay for a distance of 45 feet, while the remaining distance is not lined in any way.

The smokestack is reinforced with both vertical and horizontal steel rods, the vertical rods extending into the foundation, where they branch out like the roots of a

tree and extend clear to the top of the smokestack. The horizontal reinforcing consists of rings laid in the joints between each layer of blocks; these are well lapped and are wired to the vertical rods.

The blocks are made solid with recesses for engaging the reinforcing bars. The bottom of foundation is 8 ft. below ground grade, and is 18 ft. square. The foundation and octagonal part of the stack were built in place with wooden forms, and are heavily reinforced, while the remaining or round portion of the chimney was built of solid concrete blocks.

Iron smokestacks have been replaced by concrete in a novel manner at the plant of the Canadian-Portland Cement Company, at Marlbank, Ontario. At this plant, four stacks, each 60 feet high and 4 feet in diameter, lined inside with one thickness of firebrick, recently showed signs of corrosion in the plates. Instead of replacing with iron or steel, it was decided to coat the outside of each stack with a 4-inch layer of concrete. For this purpose a plate-iron cylinder 56 inches in diameter and 48 inches high was used as a form, and moved up the stack as the concrete, which was deposited within it, had set. Circumferential reinforcement of No. 7 wire was placed every vertical six inches in the middle of the 4-inch thickness. It is estimated that about $1,200 was saved in the construction by concrete covering, above the cost of new iron or steel stacks.

Mr. Sanford E. Thompson gives the following rules to be followed in the construction of reinforced concrete chimneys:

Rules for Design of Concrete Chimneys

1. Design the foundations according to the best engineering practice.

2. Compute the dimensions and reinforcement in the chimney with conservative units of stress, providing a factor of safety in the concrete of not less than 4 or 5.

3. Provide enough vertical steel to take all of the pull without exceeding 14,000, or at most 16,000 pounds per square inch.

4. Provide enough horizontal, or circular steel to take all the vertical shear and to resist the tendency to expansion due to the interior heat.

5. Distribute the horizontal steel by numerous small rods in preference to larger rods spaced farther apart.

6. Specially reinforce sections where the thickness in the wall of the chimney is changed or which are liable to marked changes of temperature.

7. Select first-class materials and thoroughly test them before and during the progress of the work.

8. Mix the concrete thoroughly, and provide enough water to produce a quaking concrete.

9. Bond the layers of concrete together.

10. Accurately place the steel.

11. Place the concrete around the steel carefully, ramming it so thoroughly that it will slush against the steel and adhere at every point.

12. Keep the forms rigid.

The fulfillment of these requirements will increase the cost of the structure; but if the recommendations are followed, there should be no difficulty in erecting concrete chimneys which will give thorough satisfaction and will endure.

Concrete Water Tower. The water tower illustrated in Plate 27 (at left) shows a new feature in reinforced concrete work, and another

instance of concrete reinforced by steel taking the place of the all-steel structure.

The question is often asked: Can a successful water tank be constructed of reinforced concrete? While this material has been used in the construction of both water and oil tanks for a number of years, and used successfully, the remarkable work shown in the accompanying illustration represents one of the greatest feats in this particular line ever accomplished.

The tower was built during the year 1907, at Anaheim, California. It will be noted that it is not merely a reinforced tank, but is a water tower in the strictest sense of the word. It is the first water tower in the world constructed entirely of reinforced concrete. Some idea of the magnitude of this work can be had from the following figures:

From the lowest foundation to the extreme top, the tower is 112 feet, the tank proper being 30 feet in diameter and 38 feet in height, supported by concrete posts 60 feet above the ground. The tank has a capacity of 180,000 gallons, and is made throughout of concrete reinforced with rings and vertical members of twisted steel. The walls of the tank are but 3 inches thick at the top and 5 inches at the bottom. The floor is supported by concrete beams radiating from the center; and the twelve posts, each 16 inches square, are stiffened by two lines of horizontal struts, at equal intervals above the base. The structure is graceful in outline, and yet gives a pleasing appearance of massive solidity. The cost was $11,400, or about 75 per cent of the lowest estimate on a steel tank and tower of equal dimensions. About 800 barrels of Portland cement were used.

A Concrete Lighthouse. That reinforced

concrete can successfully resist a violent earth-shock, gales of hurricane-like force, and the combined fury of sea and tides, has been most satisfactorily demonstrated in the case of the little "Mile Rock" light station shown in Plate 27 at right.

This beacon stands just at the entrance to the Bay of San Francisco—at the Golden Gate. It is located one mile from the southern mainland, and nearly three miles from the North Heads. Mile Rock light station was completed only a very short time before the great disaster that befell San Francisco on April 18, 1906. Though only a "third-order" light station, yet its total cost to the government reached $100,000.

For a great many years, Mile Rock was a menace to every vessel that entered and passed out of San Francisco Bay. A station would have been built upon this little point of rocks long ago, but for the many and great engineering obstacles that beset such an undertaking. Originally Mile Rock was a mere ragged pinnacle of rock—just jutting above the level of the sea. At extreme low tide, the highest point of this rock stood only 14 feet above the ocean's level.

Before a foundation could be secured, it was necessary to chip off a broad base, or bench, extending clear around the point of rock some distance below the highest pinnacle. The chiseling of this "rim" proved a very slow, difficult, and dangerous undertaking. During high tides and stormy weather, no work could be done at all, as the rock was practically under water or wave-swept.

Finally, with great labor and danger, a mammoth steel cylinder was built up around the rock, the base resting on the rim or bench. Owing to the shape of

the rock, this huge cylinder could not be made perfectly round, but had to be elliptical in form. It was 40 feet the long way, and 25 feet the shorter way, and was slowly built up to a height of 42 feet from its base.

The plates of this cylinder were steel boiler metal ⅝ of an inch in thickness, and were riveted together very strongly with heavy bolts. As the cylinder was being built upward, the cavity was gradually filled with strongly reinforced concrete, which was tamped down very firmly. The immense cavity in the cylinder was 25 by 40 by 42 feet, and over 1,200 barrels of cement alone were required to make the concrete for this massive foundation.

One of the heaviest gales ever known in the history of California swept for several hours over San Francisco, doing great damage to the shipping and buildings. Again it was feared that the Mile Rock station would go; but it stood—Gibraltar-like—and defied the old storm king. A subsequent examination of the concrete foundation by government engineers showed everything firm and intact—just as when completed.

Concrete Vats. Reinforced concrete is being used to a large extent for tanks or vats to contain liquids. They require careful design to see that there is sufficient steel to resist the pressure, and also very careful proportioning and placing of the concrete. A system of square tanks or vats in the basement of the American Oak Leather Company, Cincinnati, is illustrated in Plate 28. These are 6 feet by 8 feet and 6 feet deep, with reinforced walls 4 inches thick. They were built in groups of six, with specially prepared aggregates. These vats, after over a

year's service, have given entire satisfaction and show no signs of leakage.

Penstocks. A comparatively new and relatively untried opportunity for the use of reinforced concrete is presented in the construction of penstocks for the conveying of water, frequently under considerable head. A recent investigation conducted by Mr. Leonard C. Wason, of Boston, throws interesting light upon the subject. He was particularly anxious to learn whether expansion joints would be necessary with this form of construction. Literature upon concrete construction was carefully scanned as regards authoritative statements. A typical competent authority for the theory stated that reinforced concrete can be built of indefinite length if properly reinforced, and be free from shrinkage due to temperature and settling stresses.

Not content, however, with such a general statement, Mr. Wason sought the personal opinions and experiences of various engineers. Their replies are interesting as they are varied. One engineer experienced in concrete and hydraulic work showed a drawing of a penstock of curved section with flat base, laid out for continuous reinforcement from end to end without expansion joints. He emphasized the necessity of standpipes for taking care of water-hammer, air-pressure, and vacuum. After careful investigation he stated his belief that a penstock without joints, but of proper shape, with sufficient longi-

tudinal reinforcement, is practicable, and would prove satisfactory.

Another leading consulting engineer stated that he had reported adversely on a proposition for building a 300-foot reinforced concrete penstock. He was afraid of seepage and freezing.

An engineeer experienced in government work believes that, if properly designed, a penstock could be built of reinforced concrete without expansion joints.

The president of a large manufacturing company had had experience with a steel penstock 15 feet in diameter and 300 feet long, which crawled 3 inches and tore loose from the dam.

Although the chief engineer of a mill engineering firm had no direct knowledge of reinforced concrete penstocks, he had had trouble with those built of steel. These he had to cover.

An engineer experienced in the building of sewerage disposal works believed that such penstocks could be built with success, and that the leakage would be small; also that it would be essential to cover the concrete mass sufficiently to equalize the temperature.

Mr. Wason's conclusion was that it is feasible to build a penstock of reinforced concrete without joints; that care would have to be taken to make proper bond between days' work; and that, even with this care, slight leakage would be likely to occur at these joints when the penstock was first put into use. His experience in the matter of subsequent closing of leaks came

largely from the building of the notable standpipe at Attleboro, Mass. This is 50 feet in diameter with 100-foot water head. When first built, it leaked; but an application of the "Sylvester solution" to the inside stopped all leakage, and to-day the pipe is tight. In order to get these results it is necessary to have proper design and very careful workmanship.

Reservoirs. In a bulletin on the design of reinforced concrete reservoirs, issued by the Corrugated Bar Company of St. Louis, Mo., the following very pertinent general observations are made:

"The exterior walls of reservoirs must be designed as dams to resist the lateral pressure of the water, and also as retaining walls capable of holding the earth backing should the reservoir be built in excavation or the side walls be banked with earth. Reservoir walls are then practically retaining walls, and a reinforced concrete design will be superior to a heavy masonry or plain concrete structure. In fact, the features which make reinforced concrete so desirable for the construction of retaining walls make it even more desirable for the construction of reservoir walls. Briefly summarized, the advantages of a reinforced concrete design over these others are as follows:

"1. Greater stability at less cost.

"2. Lower and more uniform soil pressure.

"3. The practicability of reinforcing against temperature stresses.

"4. The possibility of using such sections as could not be constructed of the other materials generally used.

"For the construction of the roof of covered reservoirs, especially when an earth fill is to be placed upon

it, reinforced concrete, owing to its permanence, is superior to all other usual materials, as the elements of decay and corrosion are most active under such conditions.

Reservoirs of rectangular shape may be roughly divided into two classes; first, those with vertical side walls; second, those with sloping exterior walls. We are not considering those structures in which the reinforced concrete construction merely acts as a lining for the earth embankment.

"**Type 1.—Vertical Walls.** This type of reservoir is usually constructed partly in excavation; the excavated material is generally used as a backing for the walls. The backing must not, however, be relied upon to assist in maintaining the stability of the wall. It is possible that the fill may exert no active pressure on the wall; in fact, when the fill is mainly clay, it may even shrink away from the back of the wall. (Such materials as sand or other granular substances without cohesion between the particles, will, of course, exert an active pressure.) The walls then should be designed as retaining walls to hold back the earth when the reservoir is empty, and must also be figured for the water pressure, neglecting such horizontal earth pressure as may exist.

"With this type of wall it is necessary to prevent the development of a hydraulic head under the base. Adequate provision should also be made against failure by sliding on the foundation, and a projection extending into the soil should be provided in all cases.

"**Type 2—Sloping Walls.** This type of wall, which is illustrated in Fig. 95, is desirable and economical under some conditions. The deck **B-C** is carried on the buttresses or walls **B-C-D**, which in turn may be carried on a continuous footing or rest on isolated footings. When a rock foundation is available, the buttresses are built directly upon the same, and the apron **A-B** let into the rock a suitable depth. With independent footings, a

small leakage would not endanger the stability of the wall, and could easily be taken care of. This type of structure has been extensively used for dams, and has proven entirely successful."

A Great Concrete Dam. The city of Sydney, N. S. W., Australia, is at last assured against a water famine, now having a water supply for its growing population, which at the present time is close up to 600,000. The **great Cataract Dam** is completed, and the supply is derived from the Nepean and Cataract rivers.

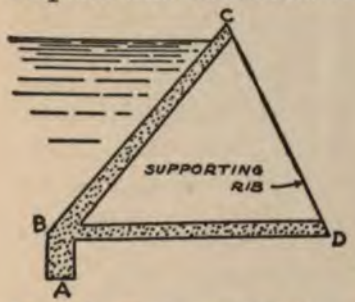


Fig. 95. Sloping Wall Reservoir.

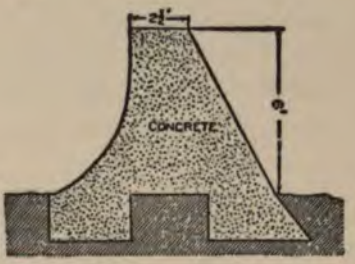


Fig. 96. One Style of Concrete Dam.

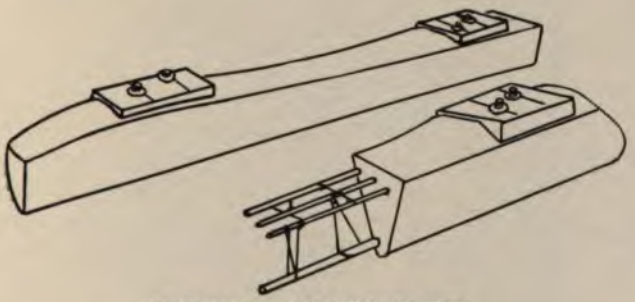
The catchment area of 354 square miles, with the good rainfall which is characteristic of the coastal districts of New South Wales, is ample for the requirements of the city, even supposing enormous expansion, but the existing storage at Prospect (only 5,446,000,000 gallons by gravitation) is quite inadequate; and further, as the water from the rivers mentioned is conveyed to Prospect by a system of canals and tunnels, having a daily capacity of only 150,000,000 gallons, the storm flow of the rivers cannot be fully

availed of, and must be increased shortly by additional works.

Occasionally, for some years back, and especially in 1902, severe droughts occurred, and the Prospect reservoir was drawn on to such an extent as to cause anxiety as to the supply. Owing to this, and to the concurrent steady increase in the population of the city and suburbs, serious shortage of water was feared; and though the citizens of Sydney were never placed on a limited supply, except occasionally in the matter of water for ornamental gardens, it was felt that, in view of the future, more of the water available during rainy years must be impounded for the city supply. For that reason, therefore, the masonry and concrete dam has been erected on the Cataract river, with a storage capacity of 21,411,500,000 gallons.

The body of the Cataract dam (Plate 29) is composed of Cyclopean rubble masonry, consisting of blocks of sandstone weighing from two to four and one-half tons, built to break joint both vertically and horizontally, and to have a maximum of bond. The stones are bedded in cement mortar, and the vertical joints are made with concrete. The proportion of blocks to concrete and mortar is approximately as 65 to 35. The up-stream face consists of concrete blocks 5 feet by 2 feet 6 inches by 2 feet, set upon and jointed with special cement mortar and backed by an average of 3 feet of basaltic concrete. The down-stream face is of concrete 6 feet thick; the foundations of the dam have been carried to a depth of 35 feet below the bed of the river in solid sandstone rock. Reinforced concrete is used in the construction

PERCIVAL CONCRETE TIES AT GALVESTON, TEXAS.

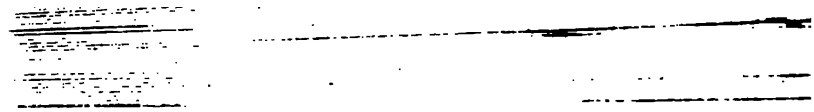


PERCIVAL CONCRETE TIE.

CORELL CONCRETE TIE.
Showing manner of fastening ties to rail.

A REINFORCED CONCRETE DOCK.

General view of South Dock, Cleveland, Ohio.



of the valve chambers at the base of the dam. The following figures give the main dimensions:

Length of dam, feet	811
Height above river bed, feet	157
Depth below river bed, feet	35
Total height from base to top, maximum, feet	192
Top width, feet	16½
Bottom width, feet	158
Maximum depth of the water, feet	150
Total storage capacity, gallons	21,411,500,000
Area covered by water, acres, approx.	2,400

Material in dam as completed:

Hearting masonry, cubic yards	111,455
Rubble masonry, cubic yards	1,975
Concrete, cubic yards	23,846
Facing blocks, cubic yards	8,966
Total,	146,242
Total cement used, tons	19,000
Quantity of excavation in connection with works, foundations, by-wash, etc., cubic yards	215,000
Ironwork in pipes, valves, etc., tons	319

Three classes of concrete were used in the dam, of which the following is the specification:

"**No. 1 Concrete.** For use in the up-stream face blocks, the lining of off-take vertical shafts, and all surfaces exposed to the water, was composed of the following proportions: Cement, 375 pounds; sand, 7½ cubic feet; bluestone and shivers, 15 cubic feet; the bluestone and shivers was in proportion of 3 parts of 2½-inch stone to 2 parts of ¾-inch shivers.

"**No. 2 Concrete.** For use on the outside of 4-foot off-take pipes, the lower valve chamber, filling cut-off trenches and tunnels and the hood of valve chamber on

down-stream side, was composed of the following proportions: Cement, 375 pounds; sand, 10 cubic feet; bluestone and shivers, 20 cubic feet; the bluestone and shivers being of the same proportions and sizes as for No. 1 concrete.

"**No. 3 Concrete.** For use in the down-stream face of the dam, in the hearting work where voids are large enough, filling shaft, and between the backs of blocks and facing boards, were composed of the following proportions: Cement, 375 pounds; sand, 11½ cubic feet; and 3-inch bluestone, 20 cubic feet. Approved sandstone accepted in lieu of bluestone.

"**Special Cement Mortar.** For use in bedding the up-stream blocks, was composed of the following proportions: Cement, 375 pounds; sand, 7½ cubic feet.

"**Cement Mortar.** For use in bedding hearting blocks and between blocks where the space was too small for No. 3 concrete, and immediately surrounding the 4-foot off-take pipes, was composed of the following proportions: Cement, 375 pounds; sand, 12½ cubic feet.

"Where required, metal work in the form of rails, bars, or other shapes, was bedded in the concrete filling between the up-stream and down-stream facework of the dam; and the hearting blocks of masonry were carried through from the up-stream to the down-stream face of the dam in sections of concrete specially introduced for that purpose between the masonry blocks."

The contractor was permitted, for the convenience of executing the work, to carry up piers within the dam for the support of roads or cranes, to such heights as were necessary, provided always that such height, the sectional area in plan, the outline in plan, and the position in the dam of such pier or piers had been approved of by the engineer.

The lining of the main shafts, inlets from penstocks, and outlets to cast-iron pipes from the shafts, were of No. 1 concrete, 12 inches and 2 feet thick, carefully cut

and worked on the timber framing so as to make a sound surface. This work was brought up with the rest of the work, so as to insure its bonding and setting at the same time.

Immediately the framing was removed, the face of the concrete, after any inequalities or defects had been filled with special cement mortar, was coated with cement wash, two coats being used where 12 inches thick, and one coat where 2 feet thick.

The sandstone used for the blocks had a weight of 140 pounds per cubic foot, and a crushing strength of 276.3 tons per square foot on a block of 12-inch cube.

Tests of the compressive strength of all concrete and mortar used were made constantly during the progress of the work, and the following are average results:

In Tons per Square Foot

	30 days	60 days	90 days
No. 1 concrete	120.53	102.17	116.07
No. 2 concrete	70.93	70.83	
No. 3 concrete	61.16	96.81	110.77
Mortar	61.42	67.68	102.66

The cost of the works is approximately $1,650,000.

The plant used on the work cost about $166,000, half of which sum only has been included in above total cost, the balance being debited to other works on which the plant will be used.

The work of construction was commenced in October, 1902, under the system of day labor. The actual work of building the dam occupied four years and eleven months, and was carried on day and night.

Reservoir Roofs. Two of the largest roofs in the world, covering approximately 16 acres, and embodying building methods and material never before adapted to such a purpose, have been constructed at Los Angeles, California.

Each is on a city reservoir, one 10 acres in extent and the other 6, and reinforced concrete piers are used as supports. In the "Bellevue," the smaller of the two reservoirs, these piers are 47 feet long, and submerged over 40 feet; and on the other, the "Ivanhoe," 27 feet. See Fig. 97.

There is a veritable forest of piers—330 of them—in the Bellevue reservoir. Each rests on a 30-inch base, running thence to 16 by 16 inches, and finally to 12 by

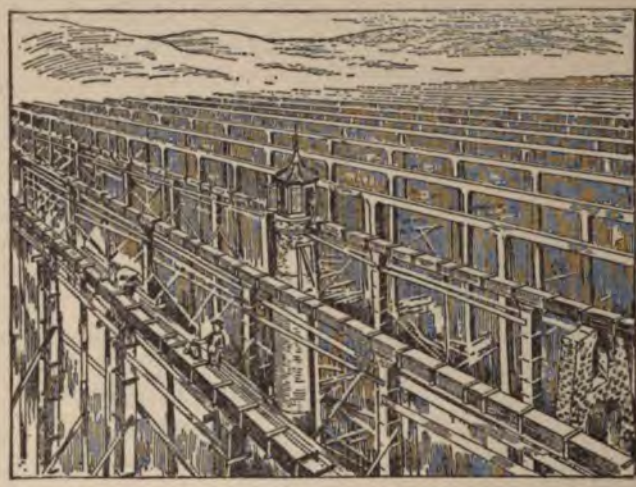


Fig. 97. Method of Roof Support for Reservoir.

12 inches at the top. The girders that span the huge "well on a hill," as the reservoir is often called because of its commanding location several hundred feet above the surrounding country, are 8 by 14 inches at the ends, 304 feet long at the widest part of the tank, and 115 feet at its narrowest—and all of reinforced concrete. The roof placed upon them, it is declared by the engineers in charge, will last practically forever. It is painted green, to harmonize with the landscape.

Roofing the 10-acre Ivanhoe reservoir cost approximately $27,000, and required 1,000,000 feet of lumber and 2,000 barrels of cement for the 630 reinforced concrete pillars that support the roof; 200 kegs of nails were required to fasten the timbers together. The roof is of truss construction, and 1,280 trusses are used. From either end of the reservoir the appearance is that of a row of 19 house roofs of great length, the base of each truss frame being 40 feet.

Concrete Conduits and Sewers. In regard to the use of reinforced concrete in the construction of conduits and sewers, the Corrugated Bar Company of St. Louis makes the following statement:

"Concrete has been extensively used in the construction of conduits and sewers, and its use is becoming more general. No one questions its suitability for the construction of aqueducts, conduits, and storm sewers; but doubt is sometimes expressed as to the ability of concrete sewers to withstand the possible action of acid sewage. This is a question that has been investigated by sewage experts; and the adoption of concrete for the construction of sewers in many large cities, in some cases after exhaustive tests to determine its value as compared with brick construction, shows the confidence that engineers place in this material.

"The following extract from an article on 'Cement Sewer Pipe,' by Rudolph Hering, may be of interest in this connection.

" 'It should be added that the acid question must be viewed in a reasonable light. When the dilution by sewage is sufficient, the discharge of a small amount of even strong acid will not cause objectionable effects, as evidenced in European cities by the use of concrete sewers almost exclusively in some cities, as Paris and

Vienna. In England, concrete sewers are also very common.'

"Many American cities have adopted concrete or reinforced concrete for the construction of large and important sewers, and the following list refers only to the more important works: New York, Jersey City, Harrisburg, Wilmington, Cleveland, Duluth, New Orleans, Louisville, and St. Louis.

"Concrete inverts have proved in practice to be equal, if not superior, in durability to the best hard-burned brick.

" 'The hardness and smoothness of surface obtainable with concrete reduce the friction to a minimum, and render it less liable to erosion than are other materials. Concrete sewers built in Duluth, Minnesota, furnish a practical example of the ability of Portland cement mortar to resist erosion. After twenty years of wear, they show no appreciable deterioration or enlargement in diameter, while brick sewers laid at the same time required rebuilding after six or seven years. A section of the Duluth drains, about 2,000 feet long and 4 feet in diameter, was built on a 13 per cent grade where the velocity of the water was 42 feet per second, with an invert of flat granite flags laid with 1:1 Portland cement joints. The flow of water during heavy storms was tremendous, carrying down with it quantities of sand and boulders; but after two years of wear the invert showed ridges of mortar between the granite flags, indicating that the Portland cement mortar was more durable than the granite.'*

"In connection with the subject of acid sewage and the durability of concrete inverts, it should be borne in mind that strong acids may affect the brickwork as well as the mortar in the joints. The smooth surface and true lines that are easily possible with concrete construction, cannot be attained in brickwork. As a result,

*From "Concrete, Plain and Reinforced," by Taylor and Thompson.

the concrete surface offers less obstruction to the flow, and is less liable to erosion.

"One striking advantage of reinforced concrete construction is the possibility of successfully constructing sewers in poor ground without the heavy foundation that would be required for a brick or masonry sewer. By the use of longitudinal reinforcement, the sewer section itself may be transformed into a stiff beam capable of spanning soft spots or even openings in the supporting soil.

"Some of the advantages of reinforced concrete construction will be given:

"Concrete is not affected by ordinary sewage. A concrete sewer is durable—the surface is smooth and strong, with minimum opportunity for erosion.

"A concrete sewer has a smaller friction coefficient than one of brick or masonry, resulting in larger capacity for a given section.

Fig. 98. Conduit Reinforced with Sheet Fabric.

"Concrete can be shaped to exact curves and dimensions. This is impossible with brickwork.

"A reinforced concrete sewer can be built, as a rule, more cheaply than a brick or masonry one, and the construction is more rapid.

"A reinforced concrete conduit or sewer can be designed to withstand bursting pressure due to a hydraulic head.

"Concrete sewers, even of large size, can be moulded in advance and laid in sections when this method of construction is desirable or economical.

ncrete sewers are usually built in place; pressure ipes and small sewers—say those under three feet in r—are often laid in sections which have been n(lded in advance. This latter method of construction s economical on account of the thin sections of concrete hat may be used, accurate forms and 'shop methods' ermitting the adoption of thinner sections than could ɒe constructed in place."

For cuts of sewer construction, see frontis- iece and Plates 22 and 23.

Fig. 98 shows the method of reinforcing a nall conduit with sheet or wire fabric.

Concrete Shaft Lining. In Plate 24 is shown an interesting piece of reinforced concrete construction. The conditions under which the work was done, and the excessive loading on the concrete, were far above the normal.

In sinking a shaft through limestone rock for the Detroit Salt Company, the contractors experienced considerable difficulty from small streams of water coming under a high head through small fissures into the shaft. After vainly endeavoring to stop these leaks in various ways, it was decided to use a reinforced lining for the purpose.

The first section of lining was placed in a section of the shaft about 250 feet from the surface. It was 2 feet in thickness, and was reinforced with 1-inch Gabriel complete trussed rods, placed 4 inches on centers, ⅝-inch top rods being placed on the same centers. In order to shorten the span the shaft was divided by struts into three sections. These struts, owing to the necessity for economy of space, were made of structural steel I-beams,

great care being taken to get as near a perfect bearing as possible at the ends. In lower portions of the shaft, where pressure is higher, the reinforcing rods were placed 2 inches on centers, and the slab thickness was from 27 to 30 inches. In these lower sections a hydraulic pressure of about 30,000 lbs. per sq. ft. was successfully resisted with no measurable deflection—a feat that seems almost incredible.

Mine Tunnel Support. A cement mine support, claimed to be impervious to fire, water,

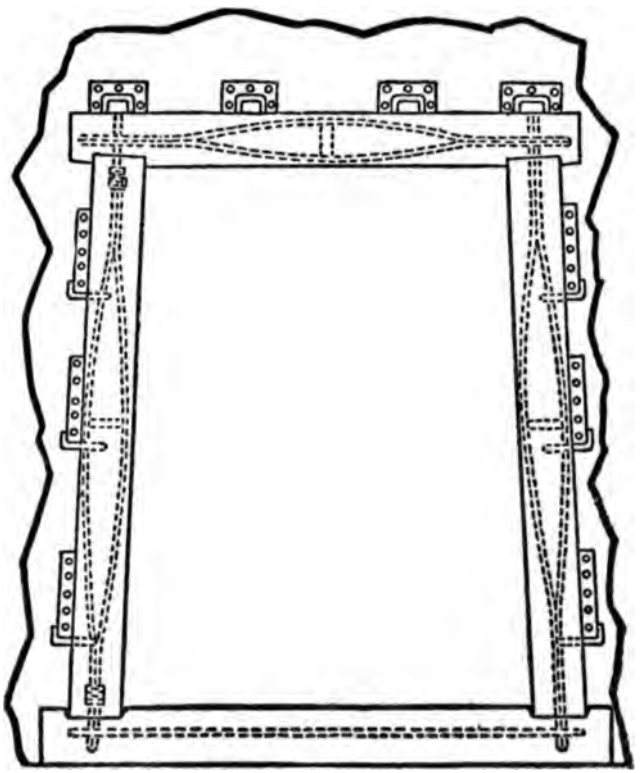


Fig. 99. Mine Tunnel Support.

and wear, has been devised by a Colorado inventor.

Instead of the rough-hewn timbers cut from the mountain side, adjacent to the property, a support said to be superior and costing much less is offered in the concrete article. The supporting frames and cross-piece have been brought to such a stage that the breaking strength has been increased to a point many times beyond that of the strongest mine timber of triple the size. The reinforcing rods are made in the form of a simple truss, and so placed that the pressure will be directed against the apex. These rods are not, necessarily, large in section, as the surrounding body of concrete supports them against the lateral bending. See Fig. 99.

The inventor claims that the cost of construction is from 10 to 15 per cent less than that of the ordinary timbers, when the latter are easily available. For an ordinary drift it sets 3½ feet by 6 feet; the posts are made 4 inches by 5 inches in size; and the caps are 4 inches by 7 inches. In these, a reinforcing loop, made of ½-inch iron rod, is embedded. In the posts the rod extends above the upper end sufficiently to pass through a hole in each end of the cap. Nuts are screwed on the ends of these rods to hold the cap in place.

The invention provides strength against lateral pressure for the members of the supports, this being the vexing question; for while reinforcement by the use of straight rods would meet requirements in ordinary construction, in this

case it was necessary to devise some method by which the lateral strength of the beam could be increased, while at the same time the reinforcing member would be confined to a narrow space.

Concrete Railroad Ties. The problem of the future supply of ties is one of the most serious that confronts the railroads. It should be remembered, too, that the widespread building of interurban trolley lines throughout the country has also tended to drain the visible sources of supply.

The life of an ordinary hewn tie is not more than two years. Sawed ties do not last as long as that. This means that every tie in every railroad system of the country has to be renewed every two years. The forestry bureau of the United States Government has information that there are not enough trees in the country now to supply the demand. So serious is the situation that the Pennsylvania Company, in 1902, commenced planting locust trees along its lines, setting out 480,000 of them, and it is the intention to set out 800,000 more.

But there is a solution to the problem. Cement has been found by actual tests to make the best possible tie. It makes a tie, too, that will not wear out and never have to be renewed. Experiments on a number of roads have proven the actual serviceability of cement for this purpose. In an interview some time ago, the chief engineer of one of the large trunk lines said:

"There have been many fitful attempts to make a satisfactory concrete tie. The idea that concrete will not stand the shock of impact under heavy and high-speed trains is erroneous; for blocks of concrete, even without steel, when properly designed and arranged, are capable of supporting the heaviest traffic. The French roads in Indo-China have been using concrete for some years and to a large extent.

"The design here described (the 'Percival,' Plate 30) was completed and first put in track in November, 1901. It consists of two blocks of concrete, each three feet long, placed symmetrically under each rail so that the center of pressure and the center of figure of each section will coincide.

"These two blocks of concrete make one tie and are rigidly connected by being moulded on the ends of a pair of three-inch channels weighing three pounds per foot. The channels are back to back, and spaced two inches apart in the clear. The concrete blocks are seven inches thick and nine inches face; and the cross-section is the same as that of a timber tie hewn or slabbed from a log about eleven inches in diameter. It presents the appearance in the track of an ordinary tie with a piece 2 feet 11 inches long cut out of the center. Hardwood blocks three inches thick, nine inches wide, and eighteen inches long, designed to cushion shocks, distribute pressure, support derailed trucks, and serve as spiking blocks, are secured to the top of the concrete blocks. Each hardwood block is, of course, centered transversely to the line of the rail.

"Cast-iron sockets that also serve to space and connect the channels are moulded in place in the concrete, and serve as an anchorage for holding down the hardwood blocks. These sockets receive suitable bolts, head down, so that when they are slipped to place and the holes through which they are introduced have been plugged they cannot be withdrawn. The first ties put in

have been in service over four years and small lots have been put in from time to time since. The last were put in the track of the Chicago & Alton Railway in October, 1905. Of all the ties put in from the first to the last, none has failed. Three and one-half years ago 1,700 of these ties were put in the track of the Pere Marquette Railroad in Bay City, Mich. The ties were put down on a concrete bed; and each tie was set to the grade, being embedded in a joint of cement mortar. The rails were then spiked down and the track filled in."

But outside of all matters of a shortage of supply of wooden ties, there is a still more important aspect to the question of using cement ties as against wooden ones. The loss of life that has resulted from the drawing of spikes and the spreading of rails on curves, it would be hard to estimate and awful to contemplate. The heavy equipment of the railroads of to-day is a contributing cause of the increased number of accidents. Locomotives have been built of a size and weight utterly unwarranted by the development of the tracks and roadbeds. The spreading of rails laid on wooden ties, which causes so many frightful accidents, can be traced in almost every instance, either directly or indirectly, to the spikes which are drawn out of the ties or by the cutting down of the rail into the ties.

It is needless to say that such accidents cannot happen where cement ties are used.

Another form of reinforced concrete tie is known as the **Corell.** This tie (Plate 30) consists of two reinforced concrete blocks about 28 inches long, 12 inches wide, and 10 inches thick, held in place by a steel tie-bar embedded in the blocks in slots in their top surface, and attached to the rails by bolts which hold clips to the rail flanges. The ties are said to sustain high-speed

traffic in first-class shape, to hold the track in alignment and gauge, and to show no ill effects from frost. It is claimed that they are indestructible; that they make a remarkably strong, firm foundation for the rails; that they do away with center-bound track; that they take the wheel load on central pressure; that a 12-inch contact with the ballast directly under the rails affords a much better support than is afforded by the ordinary 8-inch tie. Another claim is that these ties can be made at the nearest gravel-pit, thus saving heavy freight charges—always a large item in the cost of wooden ties.

On the question of cost, which, of course, is always a most important factor, it is said that these ties can be installed, either in new construction or to replace rotten ties, as cheaply per mile as standard white oak. The ties being 12 inches wide, it takes only two-thirds as many as of 8-inch ties, and, when once in place, they never have to be renewed.

The ties are made in hydraulic pressure machines, and are uniform in size, furnishing a much smoother and more even track than is possible with ties varying little and big; and it is claimed that this does away with swaying side motion on high speed. It is further claimed that the double-sleeper tie, as the Corell tie is sometimes called, admits of the solid ballasting of the center of the track, holding it in line and preventing it from shifting sideways; and the bolting of the rail to the ties avoids "creeping rail;"

and the tie-bar arbitrarily holds the rails in gauge.

A type of reinforced tie known as the MacMartin is used by the Delaware & Hudson Railroad.

This tie makes use of wooden cushion blocks embedded in the concrete upon which the rail rests. There are two of these wood blocks under each rail—the upper one, covering the entire width of the tie, called the "wearing block;" the under one, the "inset block," which allows the spike to be driven as at present. This lower block, 4 inches wide, is embedded in the concrete, and remains permanently in the tie, while the wearing block may be readily slipped out and renewed. This top block is held securely in place by means of a steel plate bent in the shape of a Z-bar, the lower end of which acts as an anchor holding it in the concrete, while the upper end presses down on the block. The blocks are wide enough to allow a Weber insulated joint to be spiked in the same manner as at present on a wood tie. This joint is probably as wide on the base as anything used.

This tie preserves the method of spiking now in use, and also allows the track to be gauged and shimmed as at present. The latter feature is a very important one in northern latitudes, and in this type of tie, shims may be easily placed under the rail during winter and spring. The staples in the ends of the tie are very convenient in handling.

The **Madden and Simpson** concrete tie is the type now being used by the Chicago, Milwaukee & St. Paul Railway Company. It has been in use on the main track of the La Crosse division for several years and has been found very satisfactory.

This tie also makes use of a wood block embedded in the concrete, thus allowing the rail to be spiked in the same manner as at present. The **block is 3 in. by 8 in., and is covered with a steel band which goes all around the tie. Holes are punched in this band so that the spikes may be driven into the wood block beneath it. The band thus serves as a tie-plate.**

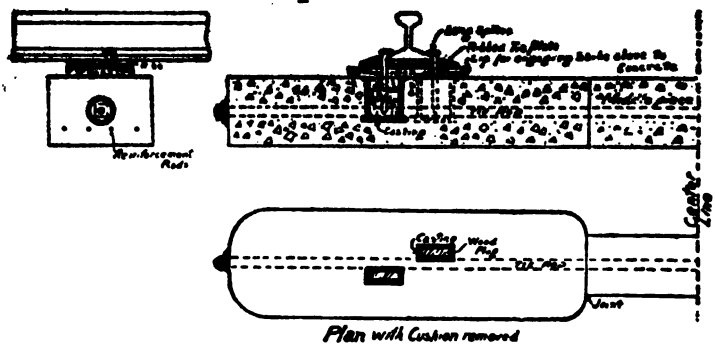


Fig. 100. Hasley Concrete Railroad Tie.

The **Hasley** tie, which Fig. 100 illustrates, has the unique feature of being made in three parts, thus facilitating handling.

The tie consists of two "foundation blocks," one placed under each rail, and a third or "filling piece" in the middle, connecting the two. The three pieces are held together by a tie rod with a nut and washer at each end.

Showing Forms for Wall.

Foundation Ready for Concrete; also Riprap Apron.

SEA-WALL AT GALVESTON, TEXAS.

FORT ST. PHILIP SEA-WALL, LOUISIANA.

For the rail fastening, hollow, malleable-iron castings are embedded in the concrete. These castings are rectangular in shape, ¾ inches wide and 3 inches long, and are plugged with wood, into which the spikes are driven in the ordinary manner. The rectangular shape of the casting allows of the adjustment of the spike lining. To act as a cushion and protect the tie from any crumbling, oak blocks are used. These oak-cushion blocks are placed immediately on top of the tie; and between the block and the rail, a ribbed tie plate is placed The plate is perforated in the usual manner so that spikes can be driven through it into the wood plugs in the malleable castings. A lip extends down from the tie plate engaging the inside spike close to the surface of the concrete, thus reducing the leverage on the spike. This lip is the same width as the spike, so that when the cushion block wears, the lip will be pushed down into the wood plug. The bearing area of the tie plate is 60 square inches, and the plate is designed to be stiff enough to distribute the weight from the rail uniformly.

Telegraph and Telephone Poles. Telephone, telegraph, and electric railway managers and investors will be interested in a new concrete pole known as the **Bailey.**

In a general way the poles are built on the plan of all armored concrete work, says the "Scientific American," though the construction is quite distinctive in character. In the body of the pole and near its circumference, equally spaced, are continuous rods of twisted electro-carbon steel especially prepared for this purpose. These rods are tied together and held in position by continuous spiral binding wires. These form the skeleton work of the pole, or the reinforce-

ment, which is then enclosed in a form into which the cement is poured.

Extreme climatic conditions of summer and winter, or the heavy demands upon strength and elasticity of a heavy pole line, leave the poles made by this process absolutely unimpaired. One of the features of the poles is their remarkable elasticity. A thirty-foot pole will deflect thirty-one inches at the top without seriously cracking the concrete. The breaking strain of the pole is figured at 5,000 pounds—three times the strength of the common wooden pole.

Carefully calculated accounts of all expenditures for labor and material in the construction show that under average conditions the first cost is slightly more than that of cedar poles. While the average life of a cedar pole is about twelve years, that of a concrete pole is practically unlimited. When a cedar pole decays, the labor cost of removing it and attaching the wires to a new pole is far greater than the cost of the pole itself. Such cost is by far the greatest item of depreciation in both telephone and telegraph properties. Indeed, this very item is perhaps the only one that has made telephone securities less desirable than railroad stocks. With cement poles, this renewal cost is eliminated.

Our forests are disappearing rapidly, and good cedar poles are almost unobtainable, and the price of those of even moderate quality is fast advancing. It is estimated that there are 40,000,000 poles in the ground in the United

States, worth $200,000,000. These poles have an average life of twelve years. More than 3,200,000 poles are required every year to replace those decayed, at a cost of from $15,000,000 to $17,000,000 a year. When it is considered that much of this may be saved by the use of concrete poles, their enormous value to the public service corporations of the country may be appreciated.

Concrete poles 150 feet high have been erected at St. Catherines, Ontario; and though they have been subjected to hard stress, not a crack or sign of one has appeared.

An electric company has completed a huge **reinforced concrete tower** 115 feet high. It will carry sixteen transmission cables across the Monongahela river at Brownsville, Pa. The United States Government regulations are such that the tower must support the wires across a span 1,014 feet long, and at least 79 feet above low-water mark. The tower is built in the form of a square. It is 8 feet 2 inches on a side at the base, and tapers to 1 foot at the top. It is hollow for a height of 84 feet from the ground, the walls being 1 foot in thickness, and reinforced with old steel rails and scrap iron. The tower is solid for the remaining 31 feet. Bedrock was found at so great a depth that its use as a foundation was impracticable. Therefore it was decided to build a concrete base, to carry the enormous weight of the structure. Concrete was reinforced with old rails, laid criss-cross, and made into a block. 30 feet square and 4 feet 6 inches deep, at the

center, with the top tapering away to 1 foot 6 inches at the edges. The false work which supported the forms and extended to the top of the tower was 12 feet square.

In a leaflet issued by the Association of American Portland Cement Manufacturers, H. L. Weber, chief engineer of the Ft. Wayne & Wabash Valley Traction Company, says:

"With electric railroads, the question of poles is becoming quite as serious as the tie question; but I believe it will be solved along the line of reinforced concrete a great deal easier than the tie question will be solved along this line. We expect to make renewals with the reinforced concrete pole, and, with this object in view, have made some experiments. Wallace Marshall, a LaFayette engineer, has also given the matter a great deal of thought. I have the pleasure of giving you the result of his experiments. Mr. Marshall says:

" 'In November, 1905, I made a box form of three sides, leaving the top open, for a test pole. It was 35 feet long. The lower five feet was ten inches square; commencing at that point, it tapered on all sides to five inches at the top. From the five-foot point, I put a triangular piece in each corner of the form about 1½ inches wide at the bottom and 1 inch at the top, to chamfer the corners of the pole. At proper places of a standard line pole for line bracket, cross-arms, and telephone box, I bored holes through the forms, put machine bolts through, and let them extend about two inches in the forms, screwing the nuts the full length of thread. In the top of the form, which was brought to a round point, I placed a 1½-inch pin in the center to leave a hole for an insulator pin. I then filled the form with concrete mixed by hand, consisting of one part cement to six parts ordinary gravel, except a facing of about

½ inch of cement and sand 1 to 3. After covering the bottom of the form about 1½ inches, I laid in the large end two ¾-inch concrete bars 25 feet long, and in the top part two ½-inch bars lapping them about 4 feet. I left them in the form six days. At the expiration of 30 days, we tested it as follows: We planted it firmly in the ground five feet deep. At 25 feet distant, we planted a large cedar telephone pole. At the level of 21 feet from the ground, we fastened a wire cable from one pole to the other, which is about the height of a trolley wire. In the center of this cable we suspended a barrel. Into this barrel we loaded steel rivets gradually, and watched results. The two poles began to bend as the load was applied. When the two were deflected about 21 inches each toward the other, I observed a small check come in the concrete pole about ten feet from the ground, and simultaneously they appeared from the cable to the ground. We immediately stopped loading, took off the ballast, weighed it, and calculated the horizontal strain, and found it to be 975 pounds. The maximum moment would be at the ground; but the guess at size we made was about right, since the concrete cracked from ground to cable at almost the same time. When the load was removed, the pole resumed its plumb position, and remains so to-day, although being used for heavy guy wires. The bolts were unscrewed before moving them, leaving the nuts imbedded in the pole. After concrete set, we screwed the bolts into the nuts, and could not loosen them with an ordinary wrench. It took several heavy blows with a sledge hammer. My conclusions were, however, that a wire ring or two of reinforcement should be placed about the pin for safety.

"'Careful estimates were made as to cost of such a pole 35 feet long if made in quantities in proper forms with material at the then market price, and gravel in pit—at $7 actual cost. Comparing that cost with present price of pine poles, and add to the latter the cost of

trimming, chamfering, framing, and painting, the concrete pole can be made for less money than the wood, provided no profit is paid a contractor. Figuring the moments on the pole tested, I found the concrete failed at just about the time the limit of elasticity of the steel was reached, proving that it would be of no value without the steel. I believe that the concrete pole is practicable, and the only reason I have not put them to a practical use has been the lack of time to do so.' "

Concrete Docks and Piers. Concrete is coming into more favor year by year for the construction of docks and piers. With their cost but little more than that of timber, and their length of service beyond estimate, it is no wonder that keen business men realize their value.

A unique concrete dock has recently been finished at Cleveland, a city which makes extensive use of the material in many forms (Plate 31). Heavy coal and ore freighters, the largest on the Great Lakes, daily tie up at the dock to unload their cargoes. Provision has been made to take care of the great strains.

The dock is constructed in two sections, north and south, one being 308 feet long and the other 511 feet long. The concrete mass rests on a foundation consisting of four rows of oak piles. Those in the outer row are 35 feet long, and those on the inner row are 30 feet. The first row is backed by a nine-inch wall of sheet piling made of three-inch plank interlocked. The space behind is filled with sand, and faced on top with a three-foot layer of stone and crushed slag, upon which the concrete rests. The heads of the piles are embedded in the concrete.

Two oak wales spaced five feet apart are on the face

of the dock, forming a buffer for incoming vessels. The upper wale timbers are a foot square, the lower ones being 12 by 14 inches. The dock is provided with cast-iron mooring posts set forty feet apart. These are fastened into the concrete by two-inch bolts fitted at the lower ends with washers and square heads. Three reinforcing rods are placed diagonally in the pier under each mooring post. The toe of the pier is also reinforced with bent rods.

A great deal of care has been bestowed on the problem of stiffening and anchoring the dock. One and three-eighth-inch rods spaced seven feet apart and cased in piping, tie the lower front and rear wales together. The upper front wale is held in place by one-and-a-quarter-inch rods spaced five feet centers and cased in pipe. The rear row of piles under the dock carries along its upper end two sixty-pound steel rails bedded in the concrete and running the full length of the pier. These rails serve to stiffen the dock, and also to tie the rear row of piles together.

Resting on these rails every seven feet, is a special casting or saddle to which the anchor rods are fastened. Each anchor rod is connected to the dock by two one-and-three-eighths-inch rods, which extend for twelve feet into the concrete mass, terminating in a washer and nut embedded near the face of the pier.

The dock is anchored by two rows of oak piles located 47 and 77 feet inland. These piles are driven in groups of two, the groups being spaced 7 and 14 feet apart, center to center, in the outer and inner rows respectively. They are tied together with steel rails in the same manner as the rear row of piles under the dock. Two rails are used on the inner row, and four on the outer row, of anchor piles. The inner and outer rows are tied to each other by one-and-three-fourth-inch round rods spaced fourteen feet apart, while the outer row is in its turn tied to the dock by one-and-three-fourth-inch

and two-inch rods spaced seven feet apart. The ends of the tie-rods are provided with nuts and washers which bear on cast-iron saddles fitting over the steel rails.

In building the dock the inner row of anchor piles was driven first, followed by each outer row in order until the face of the pier was reached. After the piles were all driven, the sheeting was placed in position and the concrete set.

The proportions of concrete mixture for the sub-aqueous work was 1:3:5, cement, sand, and broken stone respectively. For the super-aqueous work the concrete mixture was 1:3:6. High-grade Portland cement, clean sharp sand, and clean stone were used in the concrete mixture, which has a remarkably permanent look and has stood every test to which it has been subjected.

Galveston Sea-Wall. At an ultimate cost of about $4,000,000, the city of Galveston, Texas, has protected itself permanently against the recurrence of disastrous overflows due to such hurricanes from the Gulf as that of September, 1900, which destroyed a great part of the city, with the loss of hundreds of lives. The work included the erection of over four miles of sea-wall (Plate 32) along the water-front, already built, and the ultimate raising of the grade of the entire city.

In the latter part of July, 1909, the thorough sufficiency of the sea-wall as a protection to the city was demonstrated by the severest of all practical tests—that of actual exposure to a storm approaching in severity that which caused such lamentable loss of life and property in 1900. Notwithstanding the fact that the recent storm caused $2,000,000 damages along the

Gulf coast, with a loss of a score of lives, its effect at Galveston was practically nothing. For twenty hours the foot of the sea-wall was completely inundated, but only trifling damage was done to buildings in the area of protection, and not a single life was lost.

The county sea-wall is 3.5 miles long, and the government wall .87 mile, making a total length of 4.37 miles. The total cost of the county and government wall was $2,091,000. In the construction of the wall, the contractors first drove, at 4 foot intervals, four rows of round piling 40 feet long; and next, just within the outside row of round piling, there was driven a row of Wakefield sheet piling 24 feet long, forming a solid wall 1 foot thick, extending downward from the base of the wall throughout its entire length to prevent the undermining action of the waves. After the piles had been driven, a track was set up over them, and a concrete mixer followed up the pile-drivers, casting a layer of concrete over the piling tops, and, passing over the ground a second time, cast a second layer, the top of which was so finished as to form a key slot base over which the wall itself was later cast. Following up the concrete mixer, as it formed the base, was a huge derrick, which took from the cars on the tracks along the course of the sea wall, huge granite boulders, which were placed to the seaward of the foundation, a depth of 3 feet and a width of 27 feet, forming an apron riprap designed to keep the waves from cutting away sand from the front of the wall.

The wall itself was formed by large moulds, which were set up over the foundation. These moulds were 16 feet wide at the base, being same width as foundation, and 16 feet high, curving to a 5-foot width at the top. They were about 40 feet long, and the sections of the wall were cast alternately; that is, one section would be

cast, then a space left and another section cast, and so on until three or four sections would be sufficiently hardened so that the moulds could be removed and the intervening space filled in. As the moulds were filled, there were inserted reinforcing rods of steel 1½ inches by 1½ inches by 10 feet, having at each end a 4-inch washer. These reinforcing rods, placed at 2-foot intervals, were so set as to bind the narrower top of the wall to the broad substantial base.

In the construction of the county wall, which is about five-sixths of the total length, there were used 5,200 carloads of crushed granite, 1,800 carloads of sand, 1,000 carloads of cement, 1,200 carloads of round piling, 400 carloads of sheet piling, 3,700 carloads of riprap, and five carloads of reinforcing rods, making a total of 13,305 carloads of material. The weight per linear foot of the sea-wall, with its foundation and riprap, is 40,000 pounds. If the round piles, 22,289 in number, were placed end to end, they would reach 175 miles, or supply sufficient piling for a railroad trestle 10 miles long. The sheet piling would lay a floor 1 inch thick and 24 feet wide for 26 miles, or would make a plank walk 2 feet wide, 312 miles long. If the 2,134,176 cubic feet of granite boulders which comprise the riprap, were placed in a pile 100 feet square at the base, it would make a gigantic monument 215 feet high.

Fort St. Philip Sea-Wall. Plate 32 shows the Fort St. Philip sea-wall near New Orleans, La. This sea-wall was built by the United States Government as a means of protecting the back side of Fort St. Philip from the effects of high water and seepage from an arm of the Gulf of Mexico which lies about a mile back of the fort.

The length of this sea wall is 4,400 feet, and the contract involved the enlargement of 3,670 feet of old levee,

the building of 730 feet of new levee, the driving of 4,400 linear feet of steel sheet piling, and the placing of the reinforced concrete.

Work was begun December 1, 1907; and after the enlarged and newly built levee had settled sufficiently, the driving of piling was commenced. The piling was shipped by barge on the Mississippi river, the first lot arriving in March and the second in May. The piles were driven by a drop hammer weighing 2,800 pounds, with which was used a cushion hood which wholly prevented any battering of the ends. The drop of the hammer was 10 feet, and the average number of blows was eight.

The steel piles were 19 feet long, driven 14 feet into the levee and extending 5 feet above its top. The piling was specified not to be less than ⅜ inch thick, to be driven vertically and in straight lines from angle to angle of levee. Twelve-inch 38-pound United States steel sheet piling was chosen as being peculiarly fitted for the work in hand; and 4,476 pieces were driven, weighing in all 1,508 net tons.

The object of the steel piling curtain wall was to prevent seepage into the reservation from the Gulf side, and it was therefore necessary that this wall be made water-tight.

After the piles were driven, the voids in the interlock were filled with grout composed of three parts of sand and one part of cement, the result of which was to make an absolutely impervious structure.

While the soil was practically all silt, several live oak stumps buried underground were encountered, through which the piling was driven without much difficulty. But one pile-driver was used, and new high records in the driving of sheet piling were made; the minimum number of piles driven per eight-hour day was 113, and the maximum 281, a record for driving unprecedented in the history of the steel sheet piling industry.

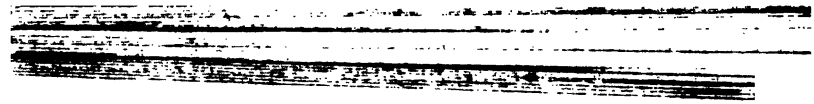
Ur r ordinary conditions, United States steel sheet ng can usually be made water-tight by wooden pack- ng strips driven with the pilings; but in order to avoid he possibility of leakage, the specifications required all iles to be heavily coated with asphaltum pitch, and this oating to be thoroughly dry before the piles were driven.

The five feet of piling which projected above ground was capped with concrete made in blocks 10 feet long. Reinforcement was of plain round steel bars, showing an ultimate strength of 60,000 pounds per square inch, and an elastic limit of not less than one-half the ultimate strength. Vertical and horizontal reinforcing rods were securely fastened with clamps. The concrete was composed of one part cement, three parts sand, and five parts of gravel or broken stone. The concrete forms were so constructed as to give a perfectly smooth surface, and no plaster or outside covering was allowed to be applied to the concrete surface after removal of forms.

Burial Vaults. Even these are now made of reinforced concrete. It was found that adjustable reinforcing forms for burial vaults was not a success; so now it is common to make them in two sizes—adult and child size. The whole body of the vault is made of expanded sheet steel centered in the highest grade of Portland cement concrete. The vault is waterproofed thoroughly after it is finished, white enameled in some instances on the inside with a waterproof paint and finished with aluminum waterproof paint on the outside. The thickness of the walls is about one inch, thus making the weight of the large vault about 1,000 pounds, the box weigh-

ing about 650 pounds, and the cover about 350 pounds. These vaults are extra strong, and can be shipped without fear of breaking.

Concrete Bath Houses. The city of Boston, which maintains a large number of floating wooden **bath houses** in the harbor, is under heavy expense each year to repair these, as they suffer destruction during the winter months. All the woodwork that can be torn away is usually carried off; the lead pipe and fittings also disappear. The extensive repairs each year has caused the chairman of the Bath Department to make a close study of reinforced concrete, which material is to be used hereafter in constructing these floating baths, and thus save much of the cost of annual repairs.



INDEX

PAGE

A

Abutment 77
Abutments 105
Abutments and Piers..... 139
Abutments, Design of..... 139
Acids, Effect of..... 56
Aggregate, Coarse 58
Aggregate, Fine..... 58
Alkalis, Effect of 56
Apartment House, Concrete. 268
Arch-Barrel 83
Arch Bridges 77
  Concrete 82
  Highway 85
  Railroad 93
Arch Centers 172
Arch Culverts 129
Arch-Ring 85
Arch Viaducts 212

B

Back-Fill 246
Ballasted-Floor Bridge..... 105
Bars, Deformed—
  Bond for 67
  Spacing of 71
  Splicing 75
Bath-Houses 333
Beam Bridges 77, 95
Beams and Columns, Length of 65
Beams and Slabs, Continuous 70
Bearing 66
Block Work 182
Boat-House of Concrete..... 278
Bond for Deformed Bars... 67
Bonding Strength and Spacing of Bars..... 71
Box Culverts 129
Brick Construction, Reinforced Concrete. 19, 160
Bridge, Flat Slab..... 96
Bridge Floors of Reinforced Concrete 157
Bridge Masonry Construction 198
Bridge Piers 148
Bridge-Seat 150
Bridges—
  Arch 77

PAGE

  Arch Highway 86
  Arch Railroad 93
  Beam 77, 95
  Classification of..... 77
  Concrete 77
  Concrete Arch 82
  Concrete, Cost of..... 220
  Concrete, Specifications for 194
  Girder and Slab..... 95
  One-Span 77
  Suspension 77
  Track-Elevation 103
Broken Stone..... 178
Burial Vaults 332

C

Cement 57, 178
Cement, Neat 48
Chimneys—
  Concrete 292
  Design of 295
Cinder-Concrete Fireproofing 2
Clamps 12
Classification of Bridges.... 77
Clips, Steel 14
Coal Hopper, Concrete..... 280
Coal Pocket, Concrete..... 285
Coarse Aggregate 59
Cold Storage Plant of Concrete 272
Columns 74
  Length of..... 65
  Plain 66
  Reinforced 66
Compression in Extreme Fiber 66
Concrete Arch Bridges..... 82
Concrete Bridges 77
Concrete Mass Work..... 184
Concrete, Mixing of..... 62
Concrete Piles, Gilbreth, Raymond, etc..... 26
Concrete and Wood Piles; Comparison 23
Concrete, Placing..... 63
Concrete Skyscraper, The First 267
Concrete Structures, Representative 264
Concreting, General Points on 188

	PAGE
Conduits and Sewers	309
Construction, Fireproof	1
Construction Work, Forms for	63, 99, 112, 113, 124, 143, 153, 171, 181, 186, 214, 250, 255
Continuous Beams and Slabs	70
Contraction	39
Contractor's Plant and Construction Work	175
Corell Tie	317
Corrosion of Metal Reinforcement	56
Cost of Concrete Bridges	220
Counterfort Retaining Wall	248
Cracks, Prevention of	39
Crown	85
Culverts—	
Arch	129
Pipe	129
Culvert Pipe, Reinforced Concrete	137
Culverts—	
Railway, Design of	134
Reinforced Concrete	128
Skew	135
Under Low Fill	135
Cut-Water	154

D

Dams, Concrete	303
Dead Load	65
Deformed Bars, Bond for	67
Definitions of Bridge Terms	83
Design, Detail, for Concrete Work	160
Design of Abutments	139
Design of Concrete Chimneys	295
Design of Railway Culverts	134
Design of Reinforced Concrete	64
Diagonal Tension	67
Docks and Piers	326
Double-Lap System	27
Double-Sleeper Tie	318

E

Elasticity, Modulus of	67
Embankment	141
Engineering Supervision	173
Expansion	166
Expansion and Contraction	39
Extrados	85

F

Face Work	165
Factory-Made Reinforcement	40
Factory, of Concrete	270
Ferro-Concrete	156
Field-Made Reinforcement	40
Filling	246
Fine Aggregate	58
Fireproofing, Cinder-Concrete	2
Fireproof Construction	1
Fireproof Floors	1
Fire Resistance	55
Flat Slab Bridge	96
Floor Construction, Vaughan System	13
Floors—	
Bridge, Specifications for	156
Bridge, Reinforced Concrete	156
Fireproof	1
Floor-Slab, Two-Way	17
Floor-Slabs	70
Footing Course	150
Forms 63, 99, 112, 113, 124, 143, 153, 171, 186, 214, 250, 255	
Placing of	28
Steel, Use of	35
Fort St. Philip Sea-Wall	330
Foundation Course	139

G

Galveston Sea-Wall	328
Garage, Concrete	278
Gilbreth Concrete Piles	26
Girder and Slab Bridges	95
Highway	97
Railway	103
Girder Viaducts	121
Grand Stand, Concrete	279
Gravel	178

H

Hasley Tie	320
Haunches, Bridge	85
Heel, Retaining Wall	248
Highway Arch Bridges	86
Highway Girder and Slab Bridges	97
Hotel, Concrete	269

PAGE

I

Insert, Socket 13
Inspection 213
Intrados 85

J

Jackson Interlocking Steel Sheeting 27
Joints 63, 135

L

Labor 217
Lean Mixture 62
Length of Beams and Columns 65
Lighthouse, Concrete 296
Line, Springing 85
Live Load 65
Load, Dead 65
Load, Live 65
Longitudinal Steel.....135

M

MacMartin Tie 319
Madden and Simpson Tie... 320
Masonry Plans, Rules for... 199
Materials and Labor..... 217
Materials—Gravel 178
Medium Mixture 62
Metal Forms..... 35
Metal Reinforcement..... 60
Milwaukee Auditorium 266
Mine Tunnel Support..... 313
Miscellaneous Uses of Reinforced Concrete 285
Mixing of Concrete..... 62
Mixture—
  Lean 62
  Medium 62
  Rich 61
  Standard 61
Modulus of Elasticity..... 67

N

Neat Cement..... 48
Notation, Standard..... 67

O

Observatory of Concrete... 276
Ocean Viaduct..... 126
Oils, Effect of..... 56

PAGE

P

Parapets 85
Pedestals 139, 150
Penstock 298
Piers 77
Piers and Abutments..... 139
Piers, Bridge..... 148
Pile Foundations..... 23
Piles 26
  Concrete, Gilbreth..... 26
  Concrete, Raymond..... 26
Pipe, Culvert, Reinforced Concrete 137
Pipe Culverts..... 129
Placing Concrete..... 63
Placing of Forms..... 28
Plain Columns..... 66
Prevention of Cracks..... 39
Proportions 61

R

Railroad Arch Bridges..... 93
Railroad Ties..... 315
Railway Culverts, Design of 134
  Footings and Struts..... 135
  Size of..... 135
Railway Girder and Slab Bridges 103
Railway Trestles..... 115
Raymond Concrete Piles... 25
Reinforced Columns..... 66
Reinforced Concrete Brick Construction 19
Reinforced Concrete Bridge Floors 156
Reinforced Concrete Culvert Pipe 137
Reinforced Concrete Culverts 128
Reinforced Concrete—
  Design of..... 64
  Fire Resistance..... 55
  Specifications 46
  Water-tightness 56
Reinforcement 67
  Factory and Field-Made.. 40
  Metal 60
  Two-Way 17
Representative Concrete Structures 264
Reservoir Roofs..... 307
Reservoirs 301

	PAGE
Responsibility and Supervision	56
Retaining Walls	246
Counterfort	248
Rich Mixture	61
Rise of Arch	85
Roofs, Reservoir	307
Rules for Design of Railway Culverts	134

S

Sand	178
Sand Test	179
Sea Water, Effect of	56
Separators	4
Sewer, Reinforced Concrete	280
Shaft Lining	312
Shear	66
Shear and Diagonal Tension	72
Shoes, Bridge	150
Shrinkage	76
Single-Span Bridges	77
Size of Railway Culverts	135
Skewbacks	85
Skew Culverts	135
Skyscraper, First Concrete	267
Slab Bridges	95
Slabs, Continuous	70
Slabs	105
Smokestack, Concrete	293
Socket Insert	13
Soffit	85
Spacing of Bars	71
Span	85
Spandrels	85
Spandrel Walls	85
Specifications for Design of Concrete Bridges	194
Specifications for Reinforced Concrete	46
Splicing Bars	75
Springing or Spring Line	85
Standard Mixture	61
Standard Notation	67
Standard Rules for Bridge Masonry Construction	198
Starling	154
Steel Cups	14
Steel Forms, Use of	35
Steel, Longitudinal	135
Steel Reinforcement	161
Stresses, Temperature	76
Stresses, Working	65
Structures of Concrete, Representative	264
Substructure, Bridge	77
Superintendence and Inspection	213
Superstructure, Bridge	77
Supervision	56
Supervision, Engineering	173
Supporting Columns	105
Suspension Bridges	77

T

Tail Walls	85
T-Beams	69
Telegraph Poles	321
Telephone Poles	321
Temperature Stresses	76
Tension, Diagonal	67
Tension, Shear and Diagonal	72
Terms, Definitions of Bridge	83
Thickness of Cover for Culverts	135
Ties, Railroad	315
Tower	148
Track-Elevation Bridges	103
Train Shed of Concrete	273
Trestles and Viaducts	115
Trestles, Railway	115
T-Section Abutment	145
Two-Way Floor-Slab	17
Two-Way Reinforcement	17

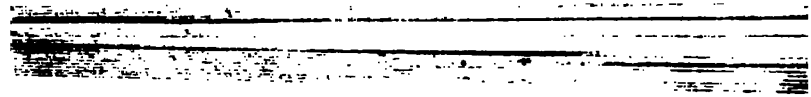
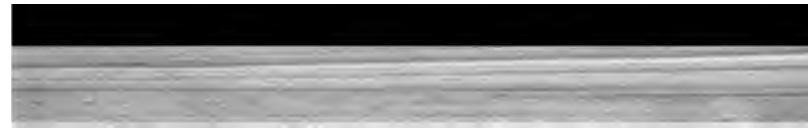
U

U-Abutment	147

V

Vats, Concrete	298
Vaughan System	13
Vaults, Burial	332
Viaduct, Ocean	126
Viaducts	115, 121
Arch	121
Girder	121

W

Walls, Retaining	246
Walls, Spandrel	85
Walls, Tail	85
Walls, Wing	135
Warehouse Construction	20
Water	60

	PAGE
Water-Intake	291
Waterproofing and Expansion	166
Water-Tightness	56
Water-Tower, Concrete	295
Wemlinger Corrugated Sheet Piling	27
Wing Abutments	141
Wing Walls	135
Working Stresses	65